ME450

Winter 2015

Final Report

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April 23, 2015

Executive Summary

The following report outlines the work we have accomplished in our mechanical engineering senior design course. This document contains the problem description and background of our project, user requirements and engineering specifications, concept generation and selection, design drivers and engineering analysis, and a description of our prototype. Finally, a discussion of our work and future plans with the project is laid out.

Our sponsor, KidsInDanger, is a non-profit organization that focuses on notifying parents of potential dangers with children's products, as well as improving children's products to reduce the number of infant injuries and deaths that occur. In 2012 there were an estimated 13, 200 emergency room visits due to high chair injuries. Through extensive research, we determined that the main cause of children being injured from high chairs is that children are being left alone and unrestrained. To solve this problem we decided to design a restraint system that was simple and easy enough to use that it will be used every time the child is in the high chair.

Our user requirements were created with the help of our sponsor, ASTM standards for high chairs, and researched customer reviews. With these requirements in mind, we began to generate concepts and start the process of selecting a viable option. After much effort we decided upon the lap bar that pivots between the child's legs.

We determined our design drivers to be prevent the child from falling, adjust to children of different sizes, allow child enough mobility to eat, and be easy to use. With these key aspects of our design in mind, a number of theoretical and empirical tests were developed. Conducting this analysis helped us improve our design while we created a CAD model and physical mockup.

With the CAD model finished we were ready to manufacture the components of our final design. The design has three primary features: a lap bar, a telescoping shaft to support the lap bar, and a locking mechanism. The lap bar was contoured to increase the comfort for the child while still denying them enough space to slide underneath. The telescoping bar provides adjustability by having the ability to change the length of the restraint system. This makes it possible to reach all the required positions to fit children of different sizes. The locking mechanism we chose is a modified ratchet and pawl system. It allows rotation in one direction of rotation, but prevents it in the other direction until it is released by a lever attached to the back of the high chair. These three components are attached to the high chair by mounting consisting of a baseplate and two side plates.

After the manufacturing and assembling was completed we conducted validation testing. In order to prove that our design was easier and simpler to use than a five point harness we recorded the number of steps and time it took to restrain a dummy using both restraint systems and found that our lap bar restraint is ten times faster. We also conducted a number of tests to prove that our design passed ASTM standards. These tests included the sharp point test, pinch point test, restraint system test, structural integrity test, and the tray integrity test. Another test we conducted was a survey to see if our design is aesthetically pleasing and marketable.

Finally, we discussed the strengths and weaknesses of our design and what we could do to improve our design in the future. There are few improvements we would like to make but overall our design was successful in being a simpler yet effective and safe high chair.

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Problem Description and Background

Sponsor

KidsInDanger is a non-profit organization that focuses on notifying parents of potential dangers with children's products, as well as improving children's products in order to reduce the number of infant injuries and deaths that occur. In 2012, there were an estimated 13,200 emergency department treated injuries due to incidents involving high chairs [1]. Our sponsor has asked us to come up with a foolproof high chair design that will prevent the child from getting injured in any way during use.

Problems with High Chairs

There are many problems with the designs of high chairs. One main problem is the ASTM standards for high chairs are optional which results in some high chairs being less safe and reliable than others [2]. However, even high chairs that follow these standards still result in numerous amounts of emergency room visits. Injuries can occur when the tray is not attached properly and weight is pressed on the unstable piece [3]. Data from the National Electronic Injury Surveillance System (NEISS) of the US Consumer Product Safety Commission reports that 94% of high chair injuries to children under three years old involved the child falling out of the high chair [4]. Most injuries involved contusions and abrasions to the head or face. An Australian study by the Injury Surveillance and Prevention Program reported that 50.8% of families reported that their child had tried to stand up in the high chair shortly before the fall [5]. Deaths are not common with only about one death per year due to high chairs, but they still can be prevented [1]. Most deaths and serious injuries occur when the child slides down the seat and is strangled by the tray or waist strap [6]. This occurred to a two year old girl who restrained herself with the waist restraint but not the crotch restraint and slid downwards [7].

Through extensive research into books, journal articles, and websites, we determined that the main cause of children being injured from high chairs is that children are being left alone and unrestrained. It seems that a reason for failure to properly secure the child is difficulty or complexity in using the safety system. Information about the restraint systems was available for less than 1% of the cases documented in the NEISS study [4]. In order to solve this problem we need to develop a restraint system that is easy to use and will always be put in place especially when the child is left unattended.

Benchmarking

In research of patents and inventions for high chairs, it was clear that the safety and security of the child in the chair is more of an afterthought. A generic opening description of a high-chair invention will start by describing the product consisting of the support features, seat, and dining surface. Methods of child security are mentioned as secondary components, if mentioned at all. It seems that the assumption is repeatedly made that a child is a perfect user, and they will simply sit in their seat politely, at all times. Any mention of improved safety refers to improved stability of the chair, preventing tipping. Most other patents and advancements in the high-chair market appear to be focused on child comfort and improving chair portability. The language in the patents hardly mention the child restraining systems the chairs employ. It is apparent that very little has been done to further improve the safety of high-chairs by preventing falls. The minimum requirements, dictated by ASTM are, that there is a restraint system and it, "shall include both waist and crotch restraint designed such that the crotch restraint's use is mandatory when the restraint system is in use." [8] yet children are still injured in high-chair falls. The bottom line is that, until now, restraining the child in the high chair has not been an area of focus in high chair innovation. Drawings from some of the patents viewed can be seen in Figure 1.

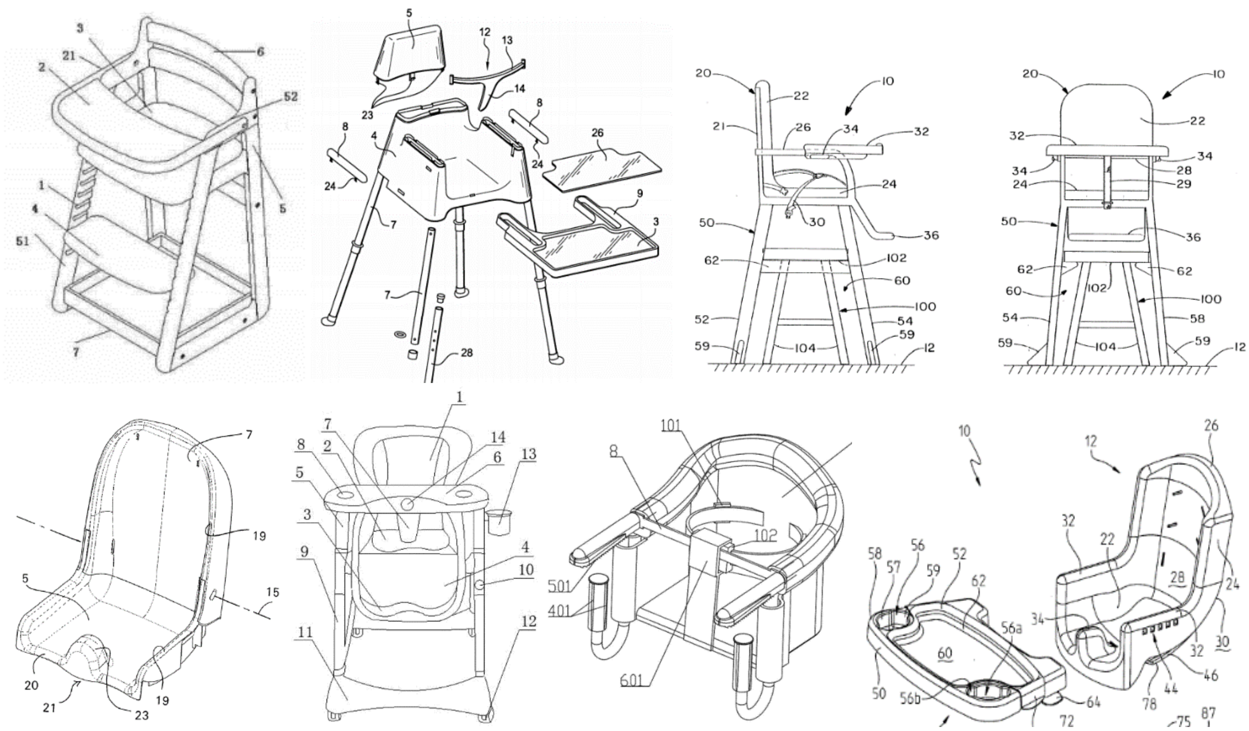


Figure 1: Images of patents for high chair innovations. None of which concentrate on the security of the child in the seat. Citations: (left to right, one line at a time) [L][K][J][B][E][G][I]

Current solutions

There are many different high chairs on the market currently. Most of these products claim to be safe for use, and employ a five point harness to keep the child restrained, as well as a bar between the legs to prevent falling through [9]. However, due to the fact that parents do not always strap their child into the chair, there is still a chance for the child to fall out. The problems with straps (5-pt harness arrangement being among the more secure types) are they are difficult to use, especially with an uncooperative child. The child is typically placed on top of the straps, then the caregiver must pull the straps out from behind the child and strap them in properly. Straps must be adjusted properly in order to be effective, and will cause pressure points and discomfort if too tight. Also, the buckle is often accessible by the child which could result in the child freeing itself from the restraint. The problems with relying on a crotch bar to prevent a child from falling through is that they may be capable of getting a leg to the other side and then falling through. A problem with relying on the end of the removable dining surface as a safety feature is it requires proper installation every time but they are not always the easiest attachment systems to use correctly. Additionally, any failure in the attachment mechanism could result in a safety failure and the child falling out of the chair. Despite the occurrences of injury from falling, little has been done to better address the security of the child sitting in the high chair.

User Requirements & Engineering Specifications

To help us with concept design and development of a successful product we interviewed our sponsor and researched standards to develop user needs and requirements [10]. We then translated these needs to quantifiable engineering specifications (Table 1). The sources from Table 1 are our sponsor [2], the ASTM standards for high chairs [8], and user reviews [9].

Table 1: List of user needs to design a successful high chair and their respective engineering specifications. The user needs are listed from highest priority to lowest priority.

	User Needs	Source	Engineering Specifications
1	Child is properly restrained	Sponsor /ASTM 6.8	At least 1 waist and 1 crotch restraint
2	Promote use of safety system	Sponsor	Uses at least 1 mechanism to prevent use when restraint system isn't deployed
3	Easy to get child in and out	Sponsor	1 step, <30 sec
4	Restraints/safety system simple and fast to use	Sponsor	<3 steps, <45sec set up time
5	Safety system easy to adjust and maintains adjustment between uses	Sponsor	<3min. adjustment to child size
6	No sharp edges	ASTM 5.1	Passes sharp point test (16 CFR 1500.48)
7	Strength and Stability	ASTM 6.4, 6.5	Withstand a gradual load of 100lb
8	No pinch points for child	ASTM 6.7	Prevent edges of the rigid parts from admitting a probe greater than 0.210 (5.3mm) and less than 0.375 in. (9.5mm) in diameter at any accessible point throughout the range of motion of such parts
9	Adjustable Restraints	ASTM 6.8.3	The waist restraint shall be capable of adjustment with a positive, self-locking mechanism that is capable, when locked, of withstanding the forces of tests in ASTM F404-14 7.8 without allowing restraint movement

			or slippage of more than 1 inch. At least 5 possible restraint positions.
10	Child cannot slide out of bottom of chair	ASTM 6.9.1.1	There shall be no vertical gap between the passive crotch restraint and either the tray, front torso support, or seating surface that allows free passage of a 1.5-in. (38-mm) diameter by 3-in. (76-mm) long rod from one leg opening to the other.
11	Easy to clean the different parts of high chair	User	Removable table, washable liner, 100% non-absorbent material, no recesses (width < 1/8 in and recessed > 1/16 in) that can store dropped food
12	Comfortable for child to sit in chair	User	cushion thickness > 0.5cm
13	Ability to fold up and store high chair	User	Footprint area reduce to <50% of in use area, when not in use.
14	Light weight	User	<30 lbs
15	Cost efficient	User	less than $150
16	Aesthetically appealing	User	Likert scale >5/10

Rationale for Engineering Specifications

1. The ASTM standard requires that the restraint system contain both a waist and crotch restraint. We are unsure of our final concept but we must at least meet this safety standard [8].

2. In order for the restraint system to be foolproof, the restraint must be used at all times when the child is in the chair. By requiring the safety system to be engaged for the chair to be used, there will be no possibility for the parent to not safely secure their child [2].

3. The system should be as easy to use as possible because if it is hard for the child to be placed into the high chair, the consumers will not want to purchase our product. We believe putting the child in the seat should only be one step and should take less than 30 seconds.

4. Restraints that are easy and quick to use decrease the probability of incorrectly securing a child. After researching current restraints we determined that an easy restraint system should be less than 3 steps and take less than 45 seconds.

5. An improperly adjusted restraint is just as bad as no restraint. The easier it is for a caregiver to adjust the restraint, the lower the chance of a child injuring themselves. After researching current restraints we determined that adjusting the restraint should take less than 3 minutes. The restraint system should also maintain the settings its set at until it’s adjusted again.

6. A high chair should not have any edges that a child can injure itself on. Sharp edges can cause injury to the child. ASTM standards outline a sharp edge test that the chair must pass [8].

7. It is important that the high chair does not tip or break when experiencing external loads. ASTM standards outline a strength and stability test to perform on the high chair [8].

8. Pinch Points that are exposed can cause injury to the child if extremities are in the pinch point and the high chair is adjusted. ASTM standard define pinch points and outline practices on how to remove them [8].

9. The high chair needs adjustable restraints that allow the restraints to fit a child comfortably and securely as the child grows. ASTM standards outline tests on the adjustable restraints and through research we found that we should have at least 5 adjustable positions [8].

10. A main safety problem with high chairs is the child's ability to slide through the chair and fall to the ground. By designing a limited gap that prevents free passage we will eliminate that risk [8].

11. A common user complaint for high chairs is that they were hard to keep clean. Children are typically messy eaters and the high chair components should be very easy for the user to clean. We believe having a removable tray, washable liner, 100% non-absorbent material, and no large recesses that can store dropped food will make the chair easy to keep clean [9].

12. Child comfort is important to the consumer, the parents. Parents are more likely to purchase a comfortable highchair than an uncomfortable one. A comfortable child will be less likely to attempt to get out of the chair. A minimum cushion thickness of 0.5cm gives enough cushioning to keep the chair comfortable and marketable [9].

13. A High chair that can fold will take up less storage room when not in use and increase product attractiveness to consumers. We believe reducing the footprint area to <50% of the using area will be a sufficient reduction of space [9].

14. The high chair must remain under 30 pounds to be easily moved from the table to storage by the parents.

15. We want to reduce cost as much as possible to make it affordable for most families. After researching other high chair prices we believe $150 is a reasonable price for a high chair [9].

16. It is important to the consumer, the parents, that the high chair is aesthetically pleasing. Using a likert scale we can survey parents to see how they like the look of our design [9].

Concept Generation

There are many different methods for generating numerous amounts of unique concepts. To begin our concept generation, we individually recorded partial concepts for different aspects of the high chair. We also each created a functional decomposition diagram which detailed the primary function of the high chair and its critical sub-functions. We then met as a team to discuss our functional decomposition diagrams and the specific sub-functions that we generated. Combining all of our work, we created a final functional decomposition diagram (Figure 2).

Figure 2: Function Decomposition for high chair

We decided that the primary function of the high chair is to elevate the child for feeding. The most critical sub-function that our project is focusing on is to restrain the child. Safety is our main goal and in order to ensure safety we must prevent the child from standing, sliding, and falling from the chair. The other important sub-functions to contribute to elevating the child for feeding, are supporting the child, holding the tray, ensuring stability, and reducing space. We used these sub-functions as parameters in a morphological analysis. By brainstorming with our previously developed partial concepts, we generated the means for each parameter in the morphological analysis table. The initial morphological analysis table contained numerous amounts of ideas especially for the restraint system. This table can be found in Appendix A (Figure A2). This table was used to combine all of our ideas into a countless amount of concepts. See Appendix A for drawings of all of the concepts for each sub-function.

Our main focus on concept generation was developing a unique and simple restraint system that could replace the five point harness. Some concepts we developed included a lap-bar that pivots between the legs (Figure 3), an overhead roller coaster-like restraint (Figure 4), a seat with leg holes (Figure 5), and a sensor that could detect when the child was standing or when the restraint strap was unbuckled (Figure 6).

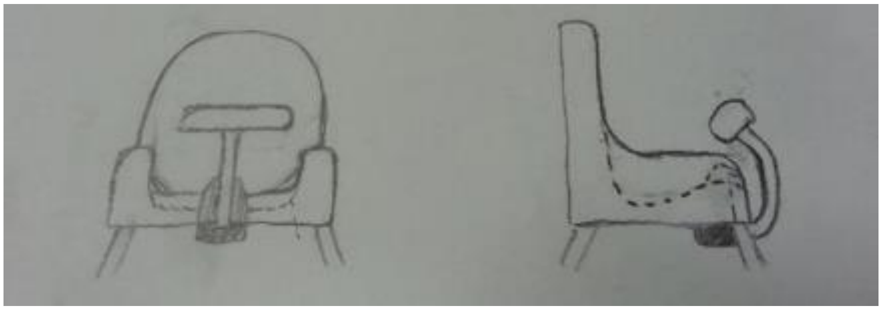


Figure 3: Lap-bar pivoting between legs

Figure 4: Overhead Roller Coaster-like Restraint

Figure 5: Leg holes in chair

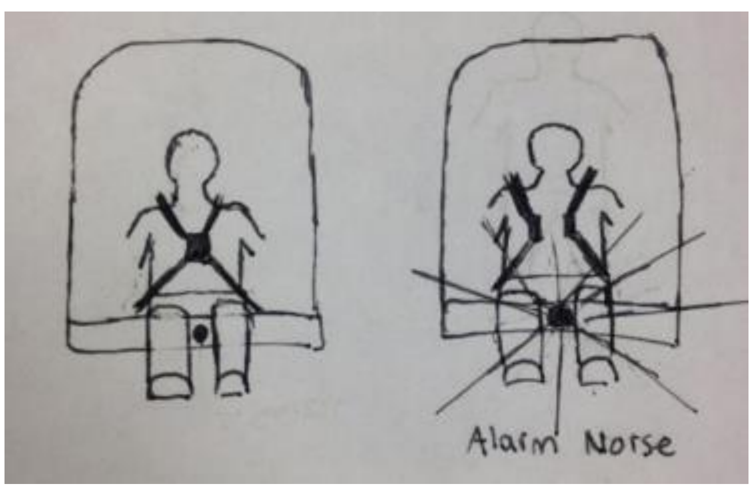


Figure 6: Seatbelt sensor to alert guardian when not buckled

The lap-bar between the legs would be a t-shaped bar that hinged from the front of the seat. The bar would lay across the child's waist and prevent them from both standing and sliding out of the chair. The overhead roller coaster-like restraint is similar to the restraint system seen on many amusement park rides. The restraint would hinge in the back of the seat and deploy over the shoulders of the child and restrain them at their midsection. This restraint would prevent the child from standing in the chair and accompanied with a crotch restraint would prevent sliding. The seat with leg holes is similar to some designs used for seats and swings for very young children. The holes in the chair would slightly suspend the child which would prevent them from falling. We also generated concepts involving sensors that could detect if the child were standing on the chair or if the child's restraint straps were unbuckled. These would be effective in alerting the guardian of danger but would not directly prevent any accidents.

Concept Selection

Scoring System

Using a morphological analysis table (Appendix A, Figure A2) generated a large number of ideas which could be combined into a countless amount of concepts. We decided to employ a Pugh chart for each sub-function to narrow down the choices. To score each concept for our safer high chair design we generated criteria to judge each idea and concept (Appendix A, Figures A31-A35). The criteria were based off of our user requirements in combination with other factors like cost, feasibility, and manufacturability. We gave each criteria a weight from 1 to 5, with 5 being most important and 1 being least important. We ranked each idea on the list of criteria by assigning them a value from -2 to 2, with 2 being significantly better than the datum and -2 being significantly worse than the datum 0.

Concept Pugh Chart	Weight	Datum	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
Simplicity of Restraint	5	0	2	2	2	2	1	1
Effectiveness	4	0	0	0	0	0	-1	0
Feasibility	3	0	0	0	0	0	0	0
Mobility of child	3	0	1	1	0	0	-1	1
Adjustability	3	0	0	0	0	0	-1	0
Durability	3	0	1	1	1	1	1	1
Cost	2	0	-1	-1	-1	-1	1	-1
Manufacturability	2	0	0	0	0	0	1	0
Simplicity of Tray	2	0	1	0	1	0	0	1
Comfort	2	0	1	0	1	0	1	1
Ease of Cleaning	1	0	1	1	1	1	1	1
Total		0	19	15	16	12	5	14

Figure 7: Pugh chart used to rank concepts and ultimately choose our final concept. The datum is a standard high chair on the market now with a five-point harness, cushion seating, four legs, rails and latch tray attachment, and a folding mechanism. Each of the six concepts is detailed further in the Appendix (Figure A37)

We evaluated and weighted the criteria for each concept shown in Figure 7 above. The reasons for our weights are shown below:

Feasibility-Weight 3-The design must be something that the parents would buy for their child, meaning it is not harmful or overly discomforting for the child. It cannot be overly costly and be ethical.

Cost-Weight 2-The weight is a 2 because safety and effectiveness are the main concerns and the parts used to make our concepts are not overly expensive.

Effectiveness-Weight 4-The effectiveness scored a 4 because if the restraint system does not effectively restrain the child then it will not perform its purpose in increasing the safety of the child.

Manufacturability-Weight 2-The high chair materials and components of current high chairs are easily manufactured and our designs don't feature exotic materials.

Simplicity of Restraint-Weight 5-The simplicity of the restraint scored a 5 because it is our main focus. Simplifying the restraint and making it easier and faster to use should cause more parents to restrain their child properly while they have them in the high chair, reducing the chance of the child falling out. The simplicity of the restraint is more important than the effectiveness because regardless of how effective the system is, if it isn't being used due to complexity then it is now fulfilling its purpose.

Simplicity of Tray-Weight 2- The tray should not be too hard to take off and put on, as this would be an inconvenience to the parent/consumer.

Mobility of the Child-Weight 3-The child should have some mobility to increase comfort and allow the child to freely move its arms to reach the food on the tray, but too much mobility poses a safety risk to the child as they may be able to stand up or slide out of the high chair.

Adjustability-Weight 3-The high chair restraint needs to be able to accommodate different sizes and weight of children to appeal to consumers.

Ease of Cleaning-Weight 1-High chairs main purpose is to hold and elevate the child during feeding. Food is likely to get on the chair and parents/consumers like easily cleanable materials. This scored a 1 because it is not that important to the safety which we are focusing on.

Durability-Weight 3-The high chair cannot fail while in use and must be durable to keep the child safe and the parents/consumers satisfied.

Comfort-Weight 2-The comfort of the child while in the chair is important to parents, and the child will be less likely to try to escape a comfortable high chair.

Concept Selection Method

Using the weighting and ranking system defined above, the concepts for each sub-function were evaluated and compared to each other in five separate Pugh charts (Appendix A. Figures A31-A35). After the preliminary analysis of concepts' effectiveness completing a sub-function, the highest scoring concepts from each sub-function were used for morphological analysis. This initial step was to reduce the number of concept combinations generated, to simplify scoring and comparison. The morphological analysis was used to generate possible combinations of sub-function concepts into different full product concepts (Appendix A, Figure A2). After reducing the field of viable concepts, morphological analysis, and engineering judgment, we generated six full product concepts (Appendix A, Figure A37). These concepts were again, scored in a Pugh chart as final products (Figure 7). From this second Pugh chart, Concept 1 scored the highest.

Final Concept

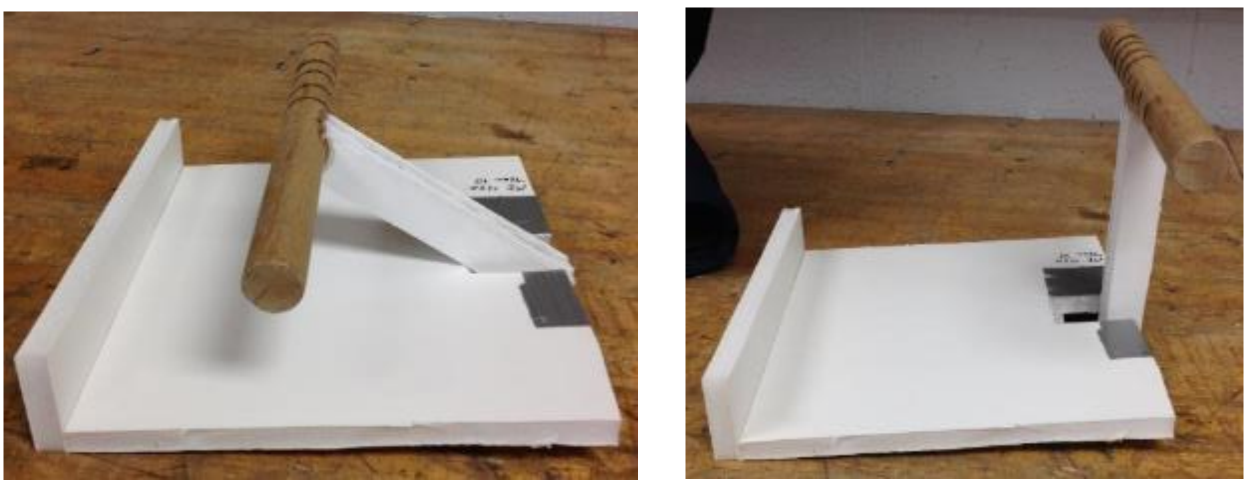
Concept 1 incorporates the lap bar pivoting between legs restraint system, cushioning over a hard layer in the seat, 4 legs for support of the chair, folding legs, and clip attachment and separate adjustability of the eating surface tray.

The advantages of the lap bar pivoting between legs restraint system are its simplicity in design, incorporating the waist restraint and crotch restraint into a single element, and its ease of use because it will be very easy and quick to operate with little effort. Disadvantages this design presents are the potential introduction of pinch-points, possible challenges in designed adjustability and the necessity to design an appropriate locking mechanism with an effectively ratcheting behavior that is still robust. The lap bar pivoting between the child's legs provides a simpler and more comfortable restraint system than the overhead roller coaster style restraint, leg holes in chair, and the lap bar that pivots from the outside of the chair. The overhead restraint will limit the mobility of the child too much and is a bulkier design that may require more effort to use. The lap bar pivoting from outside of legs is not as simple as between the legs and potentially introduces more pinch-points and steps for operation. The leg holes in chair solution is inferior to the chosen design effectiveness, comfort and adjustability.

Following the primary objective of this project, the selection process of child restraint concepts was much more intensive than for the other sub-functions. These included cushioning, support structure, tray attachment, and space reduction. Cushioning will be employed in the seat to improve child comfort but may present some challenges for cleaning and product robustness. A design employing a 4 leg support structure is the most common in the market as it affords a better combination of versatility for floor surfaces and stability, relative to 3 legs or a flat base with a single supporting element. The design will fold to reduce the space occupied when not in use. The inclusion of folding is simple because there are many different folding solutions present in market that are very effective and safe. The final concept also has the mechanisms for positioning the eating tray, relative to the seat and removing the tray, separated. This is to allow for the opening of the tray to place a child in the seat without necessitating the removal of the tray. This allows the child to be placed in the chair and removed without having to clear the eating surface each time, as is the most common case present in the market today. A disadvantage this concept presents is the need to develop and design separate solutions for both affixing the tray securely and adjusting the position of the tray, and having them work together seamlessly.

Chosen Design Mockup

We created a design mockup or model of our chosen design using foam and wooden dowels (Figures 8 & 9). This model illustrates how the restraint mechanism would function on the seat of the high chair. After building the model, we realized that the issue of pinch points caused by the lap-bar will be a problem in the future. We also gained insight on how we need to make the restraint system adjustable enough to fit many different sizes of children.



Figures 8 & 9: Final concept initial mock-up. Left: position to restrain child. Right: open position

<u>Key Design Drivers and Challenges</u>

Engineering Fundamentals

We will need to employ some engineering fundamentals to achieve the goals of our project. In order to ensure the strength and stability of our high chair restraint system, we will have to conduct basic static force analysis. This will allow us to determine the materials and dimensions required to prevent failure of the restraint system.

Design Drivers and Challenges

Our main focus is the restraint system of the high chair. The design drivers for this restraint system are safety, simplicity, and ease of use. We believe that the most challenging part of our design will be making sure that the restraint is adjustable to fit different sized children, along with creating a locking mechanism to prevent the restraint from failing. Our goal is to create a high chair that will prevent a child from falling or slipping out of the seat and injuring themselves. The difficult part about achieving this goal is that the chair must remain comfortable and serve its purpose of allowing the child to eat at an elevated level.

Major Problems Expected and Special Equipment

The major problems that we expect to encounter when developing our final concept are creating a functional locking mechanism. We plan to overcome this by researching locking mechanisms that are used in other products similar to ours. Another problem we will need to address is making sure that the restraint system will be adjustable for different sized children. We will address this by looking into the sizes of children that will use this high chair. Our design concept introduces the possibility of pinch points, which may injure the child when the restraint system is in use. Our sponsor has told us to look into different stroller designs, as this is a common problem in that area of children's products. Finally, one of our focuses with this design is to make sure that the restraint system promotes use whenever the child is seated. We plan to address this issue by somehow automating the restraint system to engage whenever a child is placed in the chair.

We will need to use some special tools to solve some of our critical problems. One of these being the Jack human modeling software. This software can simulate the movements of a child in the chair, which will allow us to make sure that our restraint system can adjust to children of all different sizes while still keeping them safe.

Engineering Analysis

To prepare for conducting engineering analysis of our design, we revisited our key design drivers. We focused more on the critical functions of a restraint system to create more specific design drivers. One design driver is that the restraint system must be adjustable to different sizes of children. This is an important design driver because the adjustability directly affects how well the restraint system will prevent the child from falling. Using research, empirical analysis, and mockup construction, we were able to determine the range of adjustability that the restraint system must achieve. The most important function of a restraint system is to hold the child and prevent them from falling. This is our primary design driver and was a source of extensive theoretical analysis. Using our results from the prior analysis, we conducted a series of static force and stress analyses to determine the dimensions and material of our restraint system. In addition to preventing the child from falling, the restraint system must also allow them enough mobility to reach the tray and eat. This is another important function that led to testing of our mockup. One of the key drivers assigned by our sponsor is that the restraint system should be easy to use. If the restraint is easy to implement then it will be used more frequently and better protect the children. This driver will be tested extensively in later studies but we also conducted a preliminary test of our mockup. Analysis of these design drivers helped us solidify our final concept design. We also conducted a failure modes and effect analysis which can be found in Appendix B (Table B1).

Adjust to different sizes of children

Empirical Analysis: To determine the adjustability of our restraint, we had to research the size of children in our target age range. From our sponsor we determined that our target age range is five months to two years old. Using the book *Child Anthropometry for Improved Vehicle Occupant Safety*, we researched different useful measurements of children in these age ranges [11]. The relevant data was compiled into a table (Table 2).

Table 2: Relevant anthropometric data of children aged 4-6 months and 2 years [11]

	Mean		5%	95%
	4-6 Months	2 years	4-6 Months	2 years
Weight (kg)	7	11.8	5.4	13.8
Waist Breadth (cm)	12.3	14.6	10.8	16.2
Hip Depth (cm)	9.2	10.2	7	12.4
Shoulder to Elbow (cm)	12.6	17	11	18.3
Lower Arm (cm)	16.9	22.5	18.9	24.8
Entire Arm (cm)	29.5	39.5	29.9	43.1
Mid-Thigh Diameter (cm)	6.88	8.05	8.05	8.98

Using this data, we were able to determine four extreme cases that the restraint must be able to reach. We assumed the smallest child in our range was the 5th percentile 4-6 month and the largest child was the 95th percentile 2 year old. The waist breadth dictated how long the lap bar must be, which was at least 16.2 cm (6.4 in). The hip depth was used to determine the distances from the back of the seat that the lap bar must reach. The mid-thigh diameter was used to determine the distances from the bottom of the seat that the lap bar must reach. These two dimensions were used to calculate the four extreme cases and what the length and angle of the bar must be to achieve these positions (Figure 10).

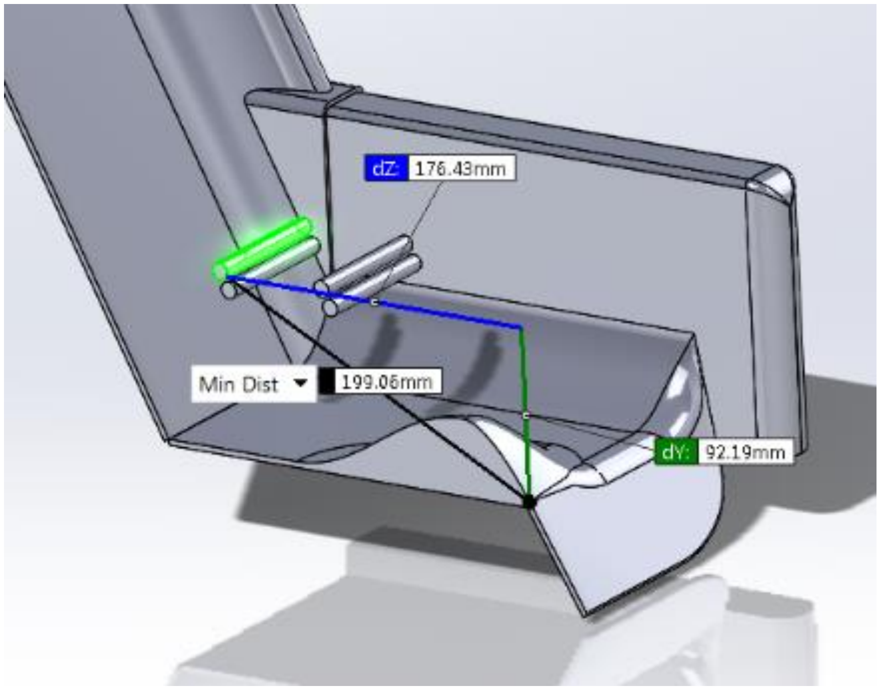


Figure 10: This image shows where the four extreme positions that the restraint must reach are located. The top left position is highlighted and the dimensions for the bar are given.

We determined that the maximum length of the lap bar should be at least 8.5 inches and the minimum length of the lap bar should be no more than 5.6 inches. The lap bar must also be able to lock in a range of angles from 26 to 42 degrees.

This empirical analysis gave us a baseline for the dimensions of our restraint and its range of motion. These measurements are subject to change once we create safety factors and begin to build our prototype. We think that this analysis has given us a trustworthy baseline for our adjustability design driver. We trust the data from our research represents the majority of children that would use our device and we believe that our device will be able to accommodate any child in this age range.

Mockup Construction: Using the data from the theoretical analysis, we decided to construct a mockup to further visualize the range of motion and adjustability of our design. Instead of starting from scratch, we made adjustments to our previous mockup. We increased the length of the lap bar rotating arm by including a representation of a telescoping feature (Figure 11). This feature will allow the restraint to reach the maximum length and make it adjustable for a variety of sizes of children. We realized that the slot in our previous model was too large so we added extra material so that the lap bar could achieve the correct height. We also added a box to represent the housing where the locking mechanism will be. The details of this design will be discussed later. Aesthetic additions were also made to the sides and legs of the chair to further emphasize the location of the restraint on the high chair.

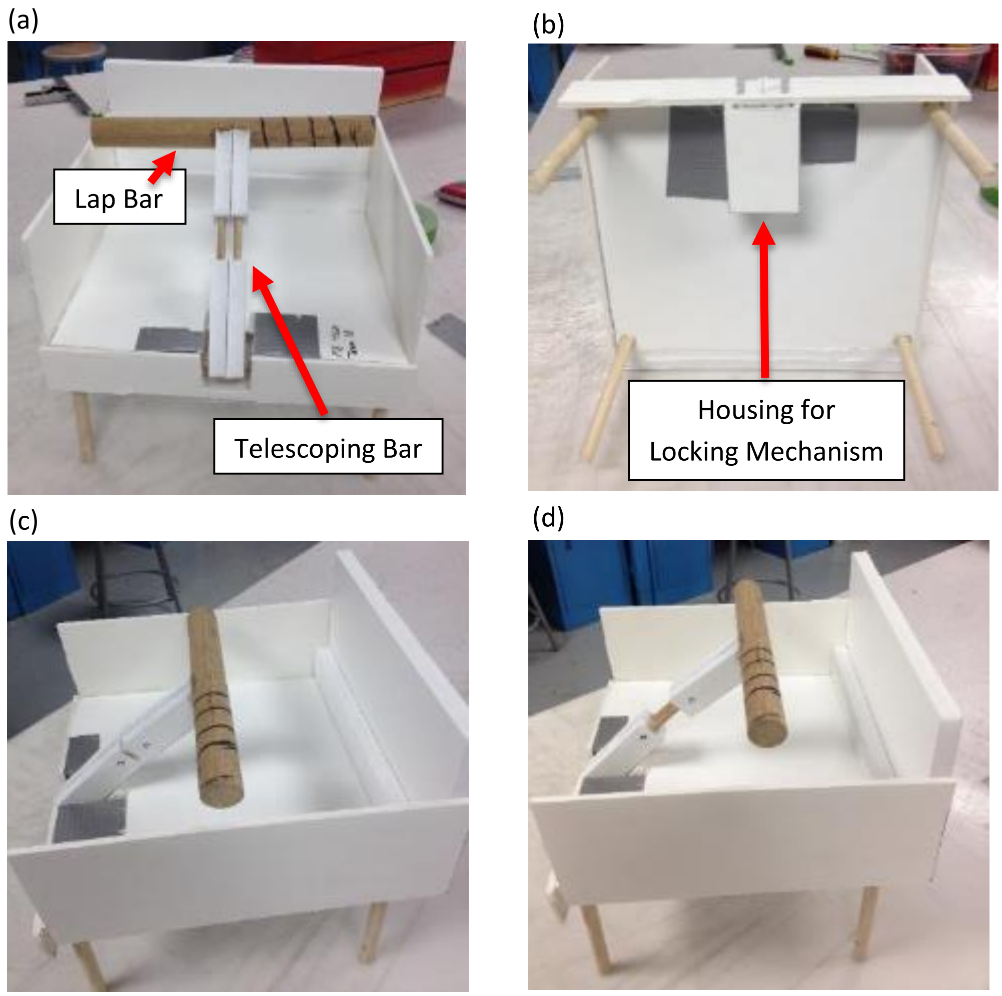


Figure 11: (a) We made improvements to our previous mockup by adding sides, a longer back and legs as seen in the front view. (b) Underneath we added a housing to represent where the locking mechanism will be located. (c) This side view illustrates the lap bar's position when the bar is not telescoping. (d) This view shows the lap bar's telescoping feature to improve adjustability.

This mockup helped us visualize the adjustability of our lap bar restraint. We were able to implement the empirical measurements and test whether the tolerances for children sizes were met. We found that our empirical analysis was correct and our mockup should be able to fit all children sizes of the ages four months to two years. Further analysis will need to be conducted once we create the locking mechanism.

Prevent Child From Falling

Theoretical Analysis: In order to prevent the child from falling out of the high chair, we had to ensure that our restraint system could withstand the forces that will be applied by the child. The ASTM standards outline a test in which 200 N are applied vertically and horizontally to the restraint system [8]. These 200 Newton values are what we used in our stress analysis. The first analysis that we conducted was a static force analysis of the lap bar. We assumed that the lap bar would behave similarly to a beam fixed at one end. We created a free body diagram of this beam with the applied forces (Figure 12). Using the lengths of the beam found from our adjustability analysis, we calculated the maximum horizontal and vertical torques, *M*, as a result of these forces. To use the bending stress equation (Equation 1), we first had to calculate the second moment of area, *I*, for varying tube sizes (Equation 2).

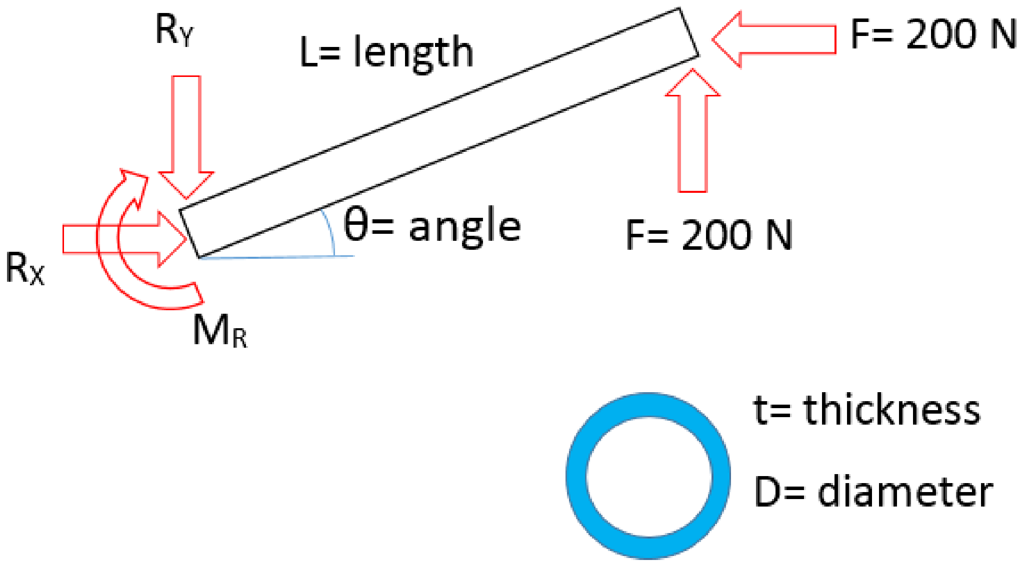


Figure 12: Free body diagram of a fixed beam representing our lap bar restraint. The bar is cylindrical and hollow. A horizontal and vertical force of 200 N is applied to the end of the beam.

$$\sigma = \frac{My}{I} \qquad \text{Equation 1}$$

$$I = \frac{\pi(D^4 - d^4)}{64} \qquad \text{Equation 2}$$

where σ is the bending stress, *y* is the radius of the bar, *D* is the outer diameter and *d* is the inner diameter.

Using various tube sizes with different inner and outer diameters we calculated the second moment of area for each tube size and used this to find the maximum bending stress. We considered PVC and Aluminum 6061 as our materials and recorded our findings in Table 3.

Table 3: Results from theoretical bending stress analysis. The maximum vertical stress for 1 in. PVC exceeded the yield strength of PVC [12] which does not meet our standards. The maximum vertical and horizontal stresses applied to all sizes of aluminum tubing were significantly below the yield strength [12] which is why we chose aluminum 6061 as our material.

Material	Diameter (in)	Thickness (in)	Max Vertical Stress (MPa)	Max Horizontal Stress (MPa)	Yield Strength (Mpa)
PVC	0.5	0.141	16.4611685	9.822666372	47.4
	1	0.1155	54.03318868	32.24254617	
	1.5	0.1535	6.679987073	3.986064803	
Aluminum 6061	0.75	0.125	68.46299875	40.85306553	193
	1	0.125	33.90548509	20.23199436	
	1.25	0.125	20.09979638	11.99389909	

PVC's thickness varied on each tube size and there was a limited selection of sizes to choose from. Aluminum provided uniform thickness and many choices of diameters so that we could easily find two that are close enough in size to perform a telescoping function. We chose 0.125 inches as our thickness for aluminum because we thought this would give our beam enough stiffness without using too much material. We varied the diameter of the tubes and found that the max vertical stress for 1 inch PVC exceeded the yield strength, which would cause deformation. This would lead to a failure of the restraint test. The maximum vertical and horizontal stresses applied to all sizes of aluminum tubing were significantly below the yield strength. Because of the range of sizes and more reliable strength, we chose aluminum as our material for the telescoping bar.

Our second force analysis consisted of determining the maximum force placed on the ratchet teeth. Our goal with this test was to make sure that the teeth would not break under the loads they will be subjected to. We conducted preliminary analysis using basic ratchet equations, which can be found in Appendix B (Figure B1). For the design and analysis of the ratchet teeth, we modeled a tooth as a cantilevered beam with a linearly varying thickness along its length, and subjected to a uniformly distributed load along its length (Figure 13). We used this diagram to calculate the stress on the tooth detailed in Appendix B (Figure B2). The resulting stress on the ratchet tooth can be seen in Figure 16. The stress applied to our size tooth is 31 MPa which is below the shear strength 207 MPa of aluminum [12].

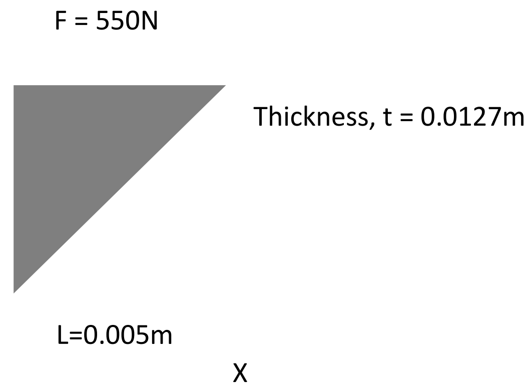


Figure 13: Free Body Diagram of a simplified ratchet tooth. 550N is the most force expected to be placed on the teeth.

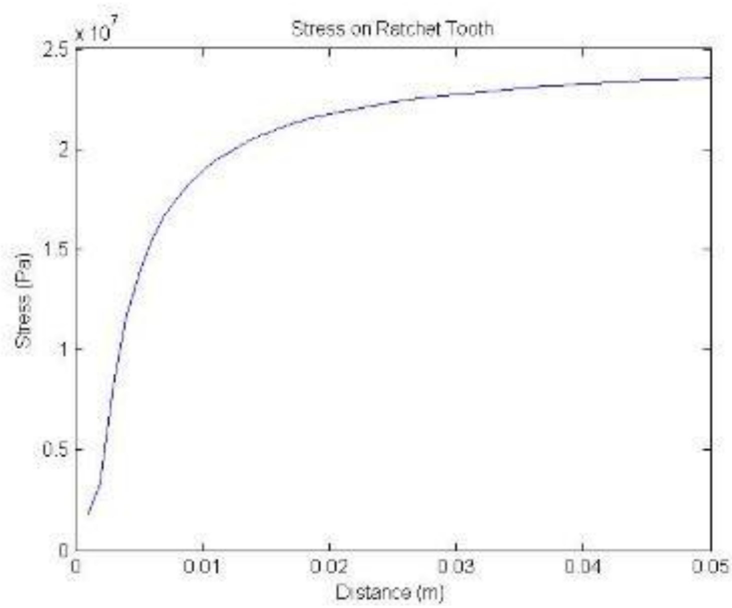


Figure 14: Plot of the stress on the ratchet tooth which follows a normal stress curve. The stress applied to our size tooth is 31MPa which is below the shear strength 207 MPa of aluminum [12].

Allow Child Mobility to Eat

Mockup Testing: We are designing a restraint system to make a high chair safer, and an important function of the high chair is allowing the child enough mobility to reach food on the tray. To ensure our design did not overly restrict child mobility, we placed our child model in the high chair and measured the distance from the back of the chair to the model's fingertips (Figure 15a). With no restraint we measured this distance to be 39 cm. We then restrained the model with the built in 5-point harness of our high chair and measured the length from the back of the seat to the model's fingertips to be 34cm (Figure 15b). Next, we placed our childlike doll in our mockup with the lap bar and measured the distance from the back of the mockup, which is identical to the high chair, to the model's fingertips (Figure 15c). This measurement was 38cm which means the child's mobility is restricted slightly but by a very small margin. Our design with the lap bar showed higher arm reach than the 5-point harness while restrained, meaning our design will allow the child enough mobility to reach food and eat on its own. All measurements of arm length were within the expected range of children 4-6 months to 2 years as seen in Table 2.

(a) (b) (c)

Figure 15: We used a stuffed animal gorilla as a model for a child. (a) We measured the distance from the back of the chair to the model's fingertips when the model was not restrained. (b) The model was restrained with a five point harness and the measurement was repeated. (c) The model was restrained with our mockup lap bar and the measurement was repeated.

Be Easy to Use

Mockup Testing: To test the ease of use of our lap bar design we timed the process of inserting and securing a child-like doll into the original 5-point harness high chair (Figure 16a). We then timed the process of inserting and securing the child-like doll into our mockup design featuring the lap bar (Figure 16b). We timed the original 5-point harness at 19 seconds and our lap bar design at 8 seconds, which is significantly faster. We only completed one iteration of each test to serve as initial data. Once the final design is manufactured, we will conduct multiple iterations of this test with more detailed procedures. The lower time required to secure the child in the high chair with the lap bar means that the parent/user is more likely to use the safety system and the child is less likely to fall out, increasing the designs safety. This test will be repeated many times as we keep improving our prototype. As the prototype becomes more detailed the time to restrain might take a little longer but we believe that it will still be significantly shorter than using a 5-point harness.

(a) (b)

Figure 16: We used a stuffed animal gorilla as a model for a child. (a) We measured the time it took to restrain the model using a five point harness. (b) We then measured the time it took to restrain the model using our mockup of our lap bar restraint.

Concept Description

Through engineering analysis and research we improved upon many features of our chosen design. This concept has three primary features: a lap bar, a telescoping shaft to support the lap bar, and a locking mechanism that allows free rotation in one direction, but not in the opposite direction.

Lap Bar

The first component is the lap bar itself. We have improved our previous concept by adding a contoured shape to the design to better fit the child's waist and legs (Figure 17). This contoured shape will increase the comfort of the lap bar on the child but it will not give them enough space to slide underneath. This contoured design is seen in many lap bars on roller coasters. The length and contour of the lap bar was determined from empirical analysis of children ages 4 months to two years (Table 2). From this data we determined that the lap bar must be at least 16.2 cm long to accompany the waist breadth of 95th percentile two year old. As an extra safety measure we made the lap bar to be 22.7 cm so that there is a very small chance of it being too short. The grooves were made to accompany the legs of a 95th percentile two year old. This will allow them to be comfortable while being properly restrained. The lap bar is made up of two pieces that will be attached by fasteners. It has a hollow interior with ribs for structural support. There is a hole in the lap bar for where the next component, the telescoping bar, will be placed. A 0.25" rod will run through the telescoping rod in the hollow body of the lap bar to prevent rotation and movement of the lap bar along the axis.

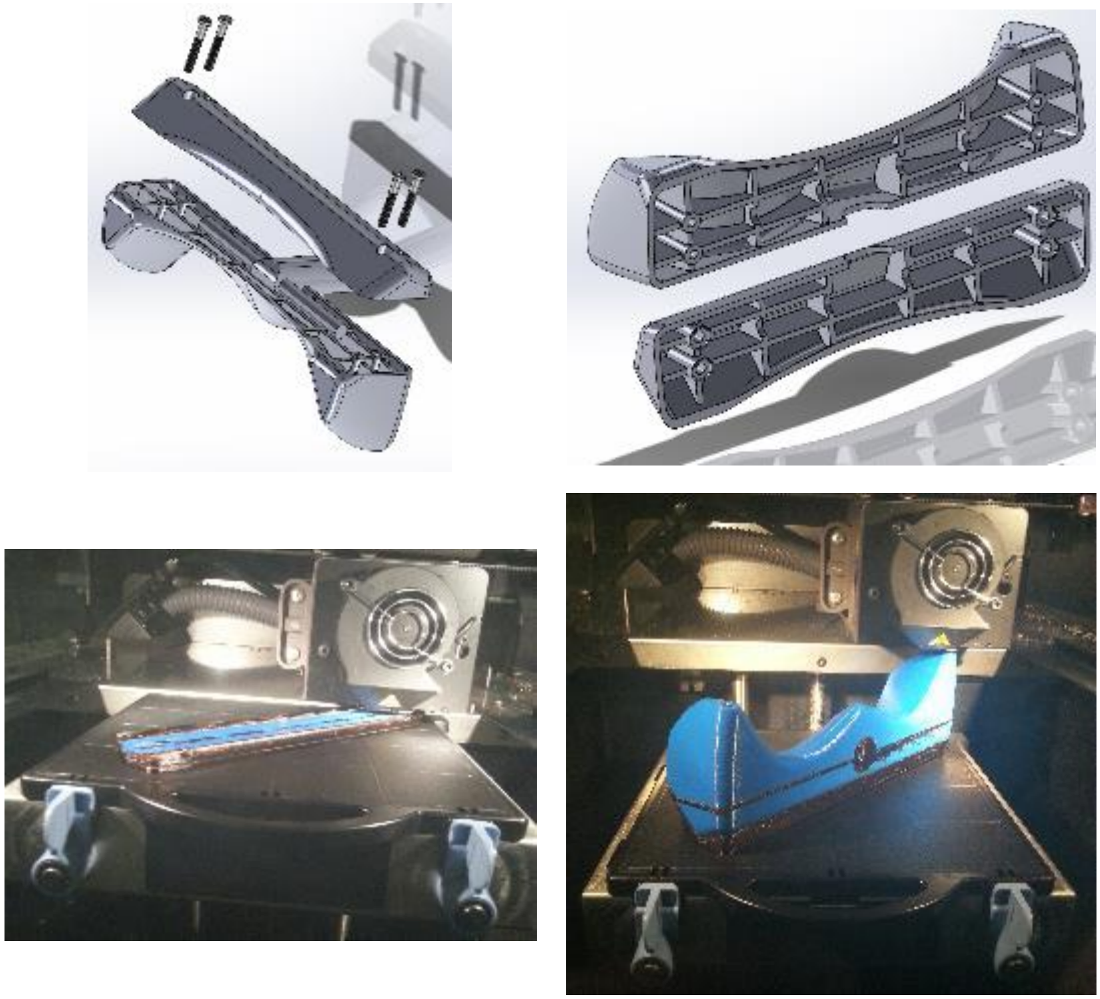


Figure 17: SolidWorks rendering of our lap bar component assembly (top left) and inside (top right). The lap bar is highly contoured to comfortably fit children of ages ranging from four months to two years. The bottom two pictures show the progress of the lap bar being 3D printed.

Telescoping Bar

The next component is the adjustable telescoping bar (Figure 18). This bar provides adjustability by having the ability to change its length, changing the range of positions of the lap bar. It was important to us to find a way to find a solution that also did not have discrete, incremental adjustment and could be set at any length within its range. This makes it possible to reach all the required positions to fit children of different sizes. The lengths that this component can reach were determined in the previously mentioned engineering analysis. The telescoping bar has a lever where the two bars connect that locks the mechanism in place. To accomplish these functions we purchased a monopod as our telescoping bar component (Figure 18).

Figure 18: SolidWorks rendering of our telescoping bar component (left) and purchased component to perform this function (right). This component will be able to telescope to adjust the length of the restraint to fit the child better.

Locking Mechanism

The locking mechanism we chose is a modified ratchet and pawl system. It allows rotation in one direction of rotation, but prevents it in the other direction until it is released. Rotation is stopped by the pawl against the teeth of the ratchet. The pawl is held against the surface of the ratchet by a spring. Ratchets have discreet points of locking because of the teeth. To increase the number of locking points per degree in our design without compromising ratchet strength, we will be using two ratchets with offset teeth placement, side-by-side on the same axis of rotation. After cutting out both ratchets, they will be pressed together on a brass sleeve bearing, then the connecting end will be machined to fit inside the telescoping bar. This component is shown in Figure 19. A cable will be run through a hole in the pawls to the back of the chair and will serve as the release mechanism. Because this design only needs a smaller range of effective rotation, the teeth have been concentrated at the necessary positions only, rather than having a full 360° gear.

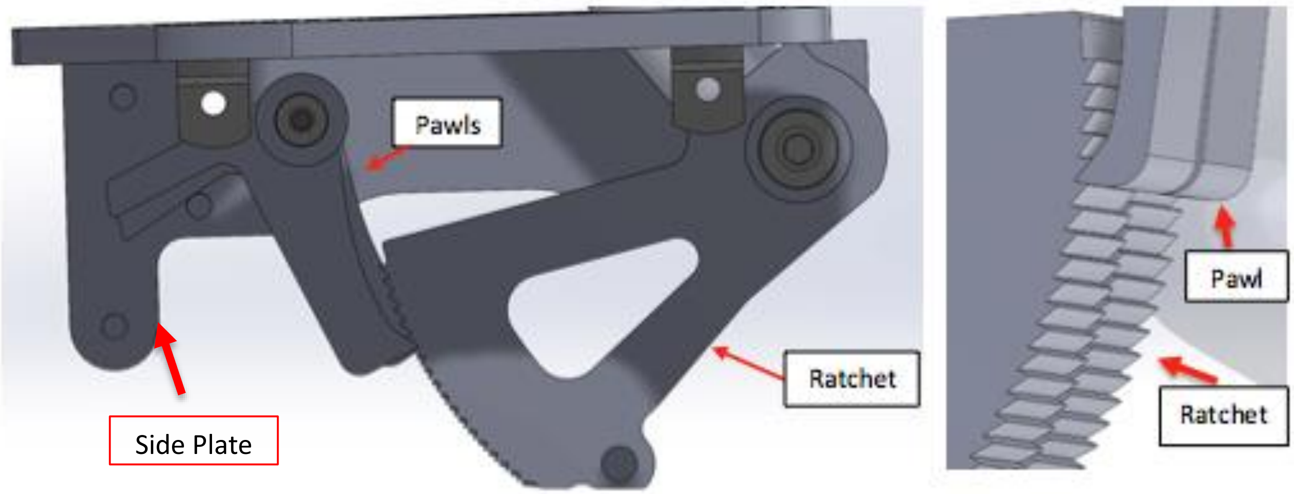


Figure 19: Close up images of SolidWorks rendering of our locking mechanism, which consists of two ratchets and two pawls. This will allow movement towards the seat and will prohibit movement away from seat once locked. There are two ratchets and pawls for more adjustability and locking positions.

Mounting

In order to mount all of these components to the high chair we designed a base plate and two identical side plates (Figures 19, 21, 22). The base plate attaches on to the bottom of the high chair using preexisting fasteners. The side plates attach onto the baseplate using L-brackets. The ratchets and pawls will be mounted on shoulder bolts in between the two side plates. The side plate also serves as the mounting point for the spring that tensions the pawl.

Release Mechanism

We needed to design a mechanism that could release the lap bar from its locked position. In order to do this we needed to rotate the pawls away from the ratchet and allow the ratchet and lap bar to rotate freely. We attached a cable through each pawl that connected to the lever mechanism seen in Figure 20. Pulling this lever will rotate the pawls and allow for the lap bar to be unlocked. The lever mechanism will be mounted on the back of the high chair, which will be out of reach of the child. The length of the lever makes it easier for the user to release the lap bar.

Combining all three of these components we can create a comfortable lap bar restraint that is able to adjust to many different sizes of children. The entire concept is further illustrated in Figures 21-23. Drawings, manufacturing plans, bill of materials and details on manufacturing can be found in Appendix C. Changes to the final design after the fourth design review are explained in Appendix D.

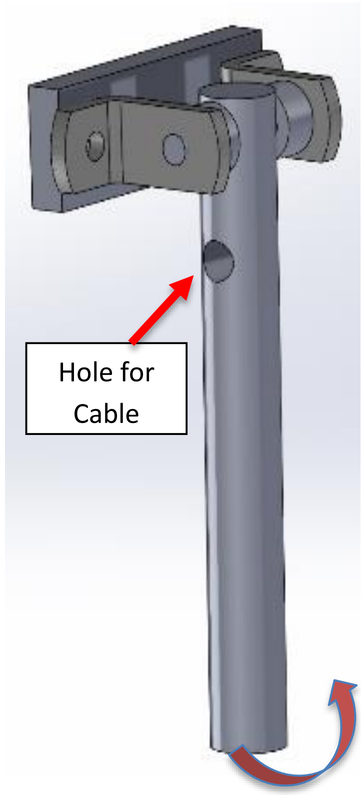


Figure 20: SolidWorks rendering of the release mechanism. A cable will attach to the pawls and run through the hole in the lever. When the lever is rotated up the pawls rotate and release the ratchet and lap bar.

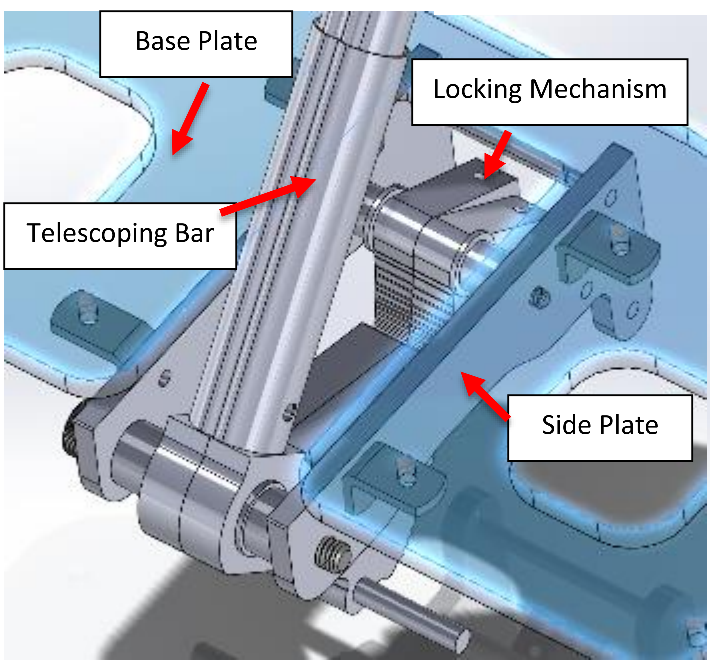


Figure 21: SolidWorks rendering of assembled locking mechanism and mounting. The design features a locking mechanism, telescoping bar and base plate and side plates.

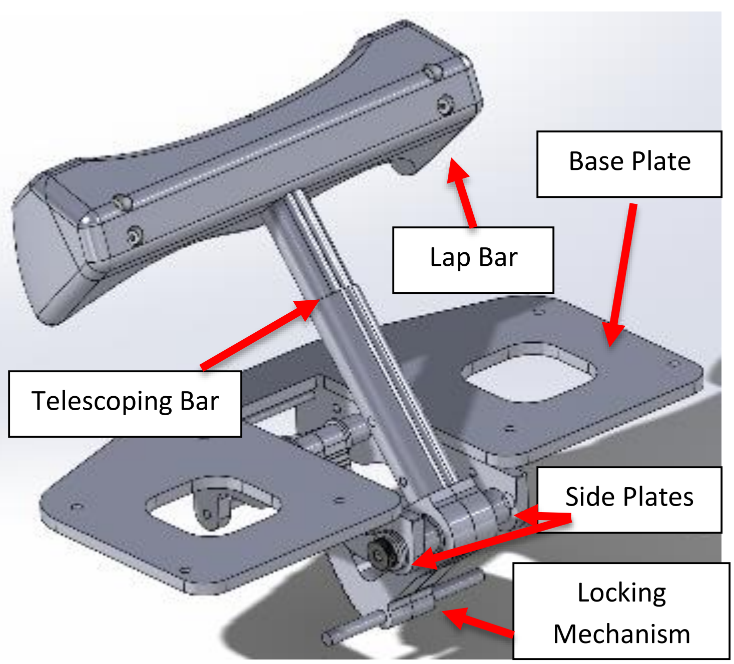


Figure 22: Close up image of SolidWorks rendering of our chosen lap bar restrain concept. The design features a locking mechanism, telescoping bar, lap bar, base plate, and side plates.

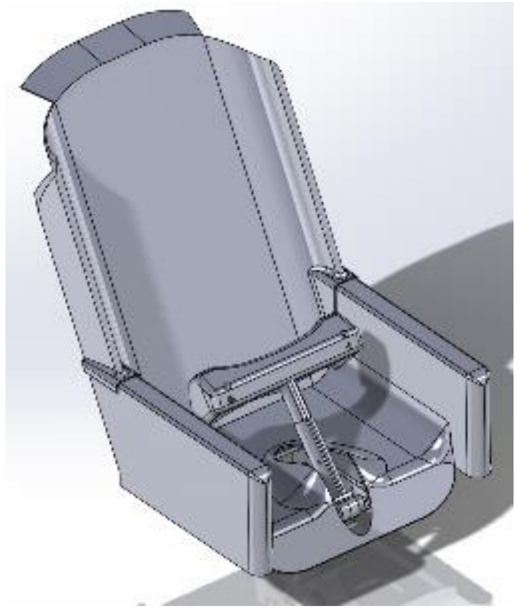


Figure 23: SolidWorks rendering of our lab bar restraint on the high chair. This shows the location of the restraint with respect to the chair and how we will modify the chair to fit our restraint.

Discussion

There are not too many things we would have done differently, given an opportunity to do the project again. We were very pleased with the end product. We feel that we could have improved DFA (design for assembly) of the prototype by tapping some holes instead of using nuts on fasteners. Additionally, we could have avoided some hold-ups experienced when water-jetting parts, which would have moved their manufacturing and assembly time-line forward by one to two weeks. This extra time may have allowed us to fully resolve and implement an additional complementary design on the prototype, to improve the operation of the eating tray.

We were very pleased with the final design. It effectively achieved each of the goals it was intended to, securely restraining a child in a high chair and substantially reducing the time required to use it. Some weaknesses in the prototype design were the release lever and modifying part of a monopod to use as the adjustable bar. While the release lever design was intended to be replaced by a more robust, more manufacturing intensive design for a final product, it was noticed during surveys and showing that many members of the public operating the design were over-rotating the lever, made possible by deformation of the molded plastic outrigger that it was mounted on. This could have been fixed by adding a stop in the lever's rotation on the prototype. In the final design, the releasing mechanism would be improved with something like a rotating cam to release the pawl and a knob under the chair and to the side, to be turned by the user. The other weakness seen in the design was the adjustable bar, made from a section of a monopod, made for a camera. The adjustment mechanism worked for demonstration, but was not child-proof nor strong enough for full implementation. Additionally, the tubing thickness was thinner than we had expected, and by their engineering approximations was not strong enough to withstand the maximum loads dictated in the ASTM standard. To fix this, the adjustable bar should be constructed strong enough to handle the necessary loads, either from metal or plastic. The adjusting mechanism should also be made stronger, not intrusive to the child, and the child should not be able to adjust it when restrained. This could be handled by a design resembling a lead screw running internally through the bar, adjusting its length when turned by a knob located at the other side of the point of rotation of the restraint. Other further improvements that could be made to the design start with fully integrating the restraint system into the design of the high chair. This would make the overall design smoother and eliminate gaps and pinch-points. To remove pinch points around the moving bar, the design could use a surface, part of the moving locking mechanism that moves coincident to the surface of the seat adjacent to it, with only the gap of a clearance fit and rounded edges between them. The ratcheting system should also be improved for production implementation to improve longevity and operation performance. This could be done numerous ways.

Appendix A: Concept Generation, Concept Drawings, and Concept Selection

Concept Generation

Functional Decomposition

Figure A1: Function Decomposition for high chair

Morphological Analysis

Restrain child	Lap bar pivoting between legs	Lap bar pivoting from side of seat back	Lap bar pivoting from outside of legs	Overhead roller coaster like restraint	Pants/leg hold that child slides into	Sensor that detects when child is standing	Seatbelt sensor to alert guardian when not buckled	Sticky Chair material
Support child	Bungie cords	Cushion	Wood	Formed plastic				
Ensure Stability	4 Legs	3 legs	3 Legs+Wheels	4 legs + wheels	Single pole + wide base			
Reduce Space	Folds	Telescoping legs	Breaks down into pieces					
Support Tray	Rails + Latch	Clips	Magnets	Tie straps	Buckles	Built in	Velcro	

Restrain child	Net that catches child	Magnets/magnetic vest	Electric shock	Inflatable mat on floor around high chair	Leg holes in chair
Support child					
Ensure Stability					
Reduce Space					
Support Tray					

Figure A2: Morphological Analysis used to generate concepts. Sub-functions from functional decomposition used as parameters.

Concept Drawings

Restrain Child

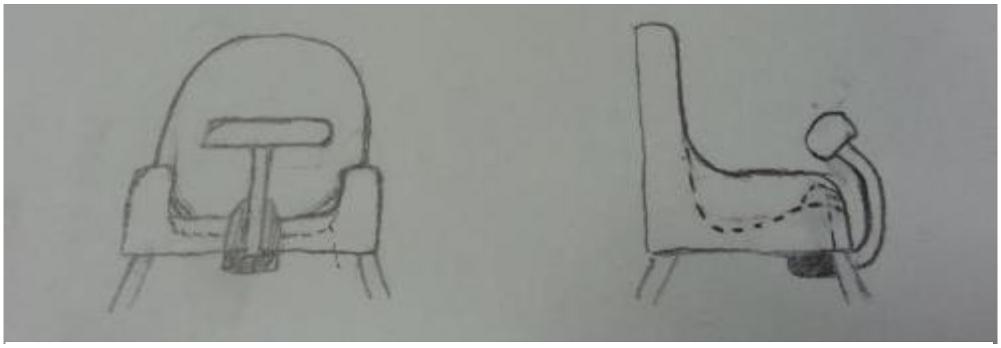


Figure A3: T-shaped Lap-bar Restraint that pivots vertically from an axis

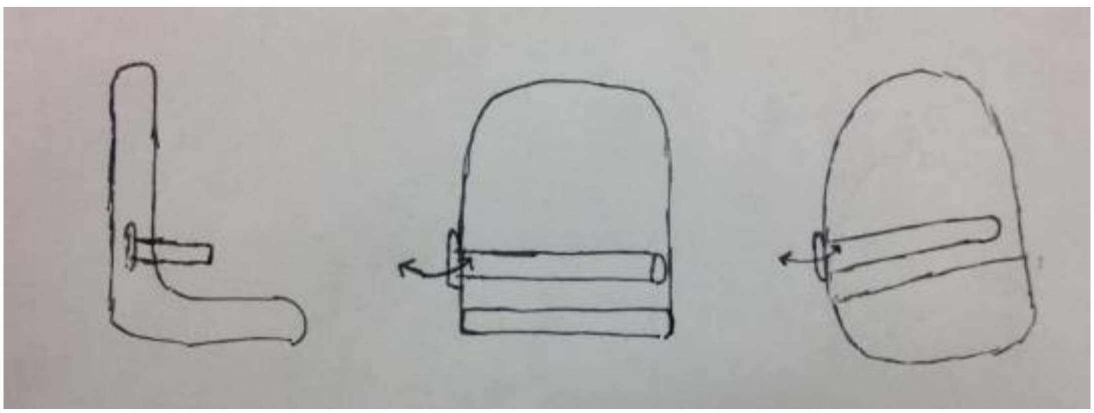


Figure A4: Lap-bar pivoting horizontally from the side of seat back

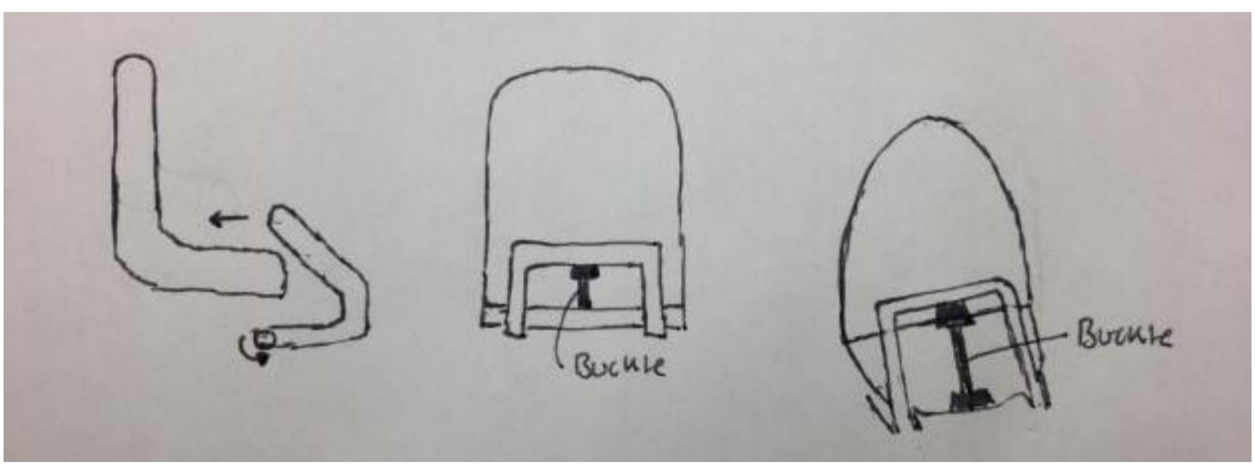


Figure A5: Lap-bar pivoting vertically from pivot points located outside the legs and has a buckling crotch strap that helps prevent sliding.

Figure A6: Overhead Roller Coaster-like Restraint that pivots from the top back of the chair and will restrain at waist and shoulders while leaving the arms free.

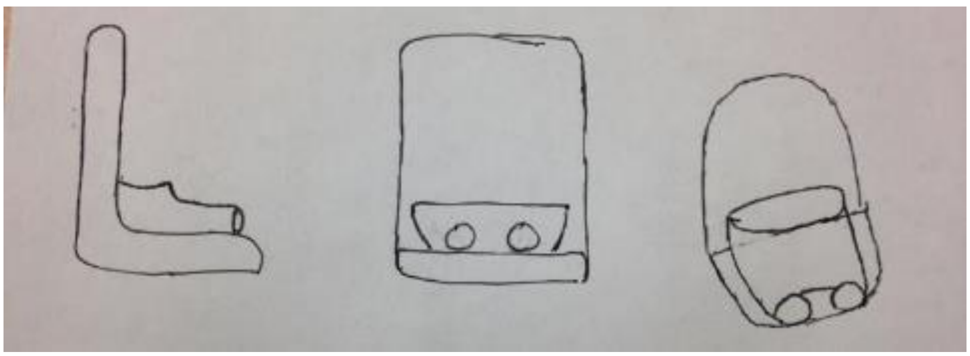


Figure A7: Pants/leg holes that the child slides into, features elastic bands around leg holes to help contain child

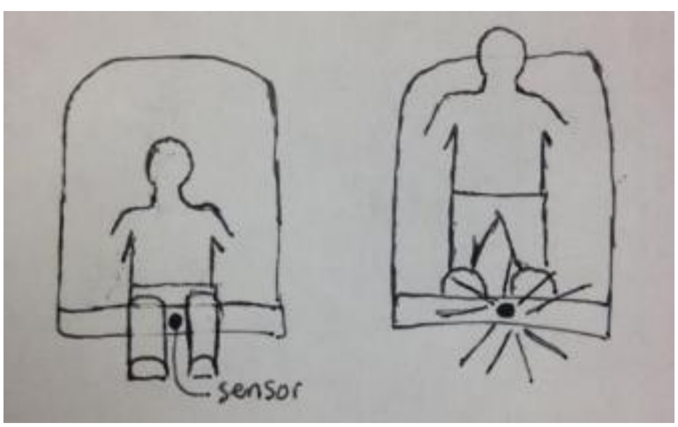


Figure A8: Sensor that detects when child is standing and alerts the guardian

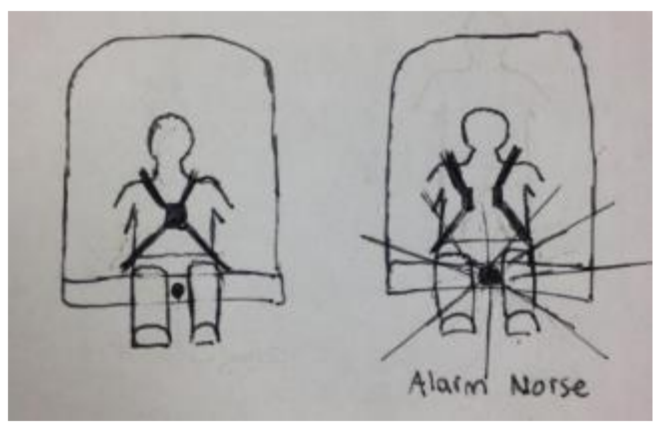


Figure A9: Seatbelt sensor to alert guardian when not buckled

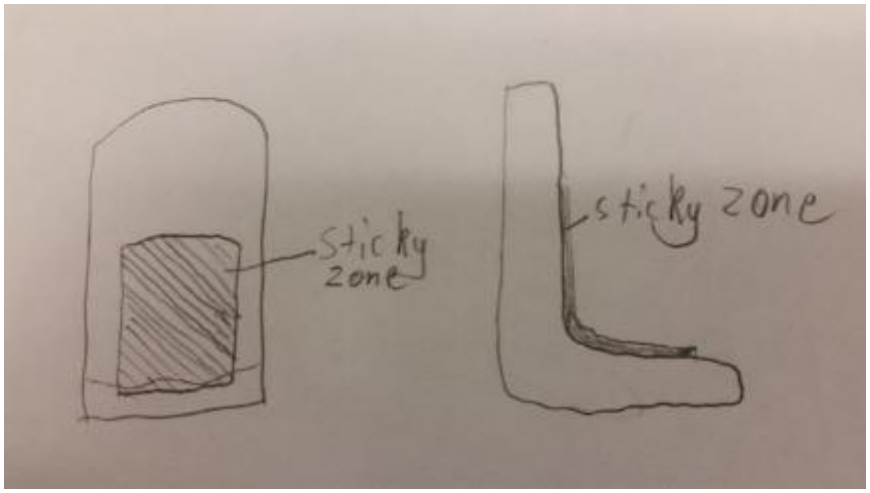


Figure A10: Sticky material located where the child will be sitting to prevent the child from sliding and falling

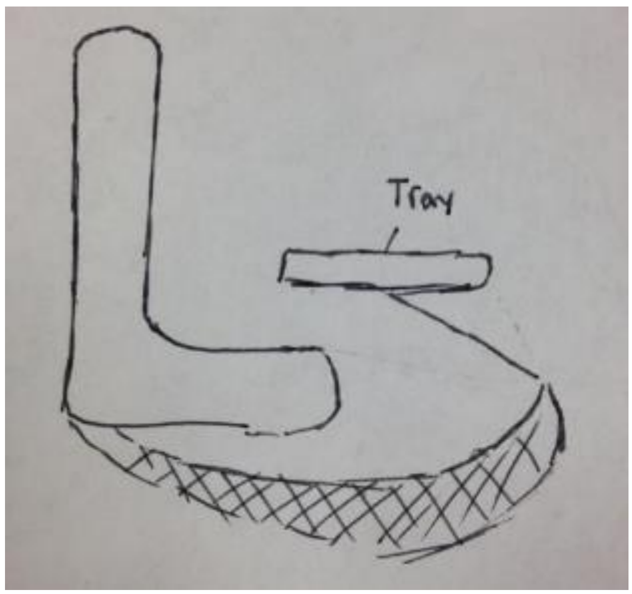


Figure A11: Net attached to the bottom of the chair and tray that catches child if they slide or fall out of the chair

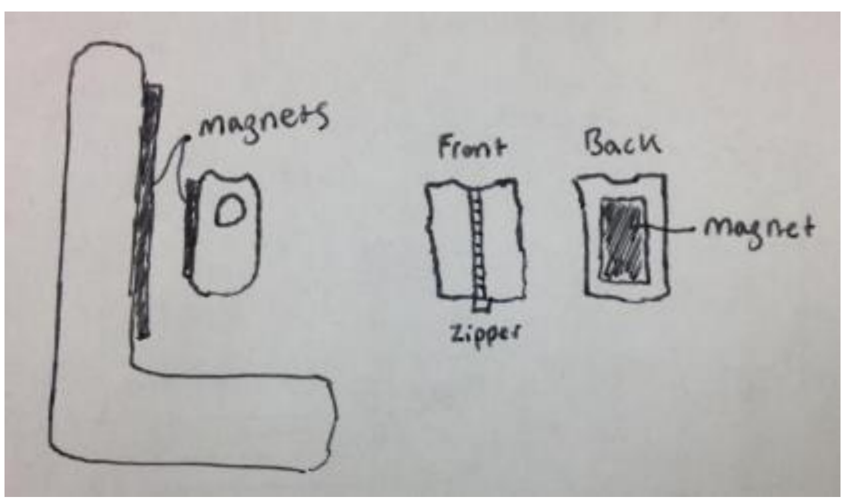


Figure A12: Magnetic vest worn by child that is secured against the back of the chair and prevents them from standing or sliding.

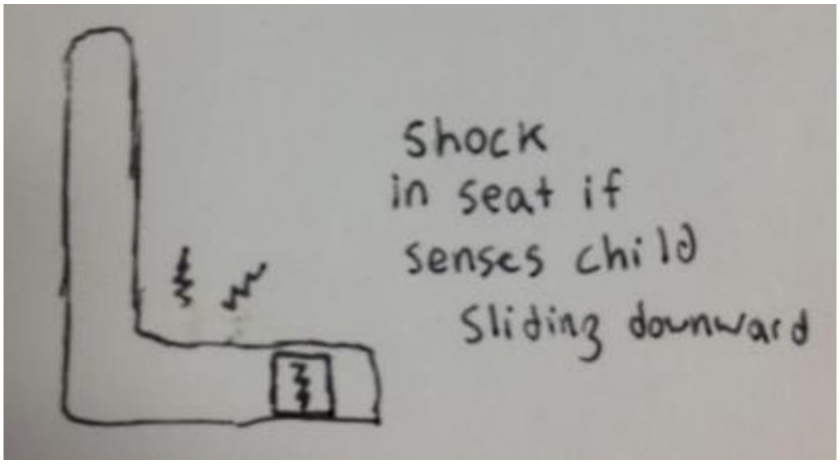


Figure A13: Electric shock

Figure A14: Inflatable mat on floor around high chair that gives the child a soft surface to land on if it falls

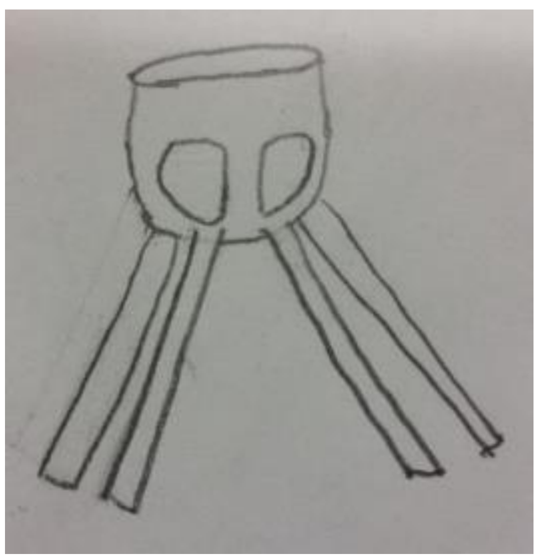


Figure A15: Leg holes in chair with a deep seat making it difficult for the child to achieve enough leverage to raise itself out of the chair by itself

Ensure Stability

Figure A16-17: Four legs and four legs with wheels

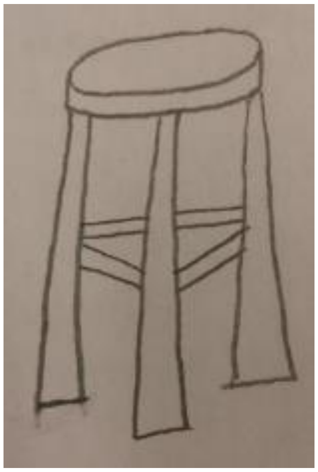


Figure A18-19: Three legs and three legs with wheels

Figure A20: Single pole with a wide base

Reduce Space

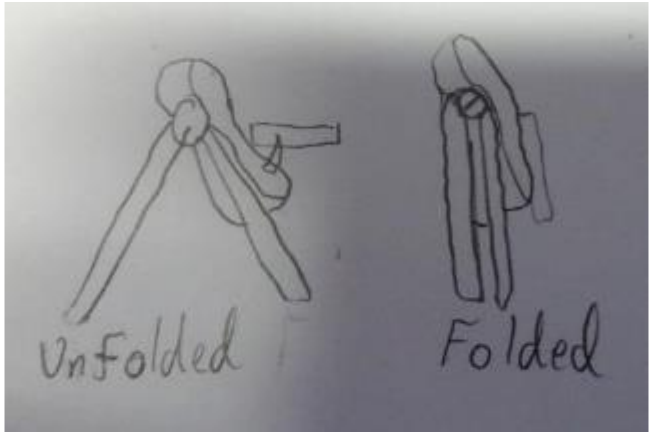


Figure A21: Chair legs fold to reduce space occupied

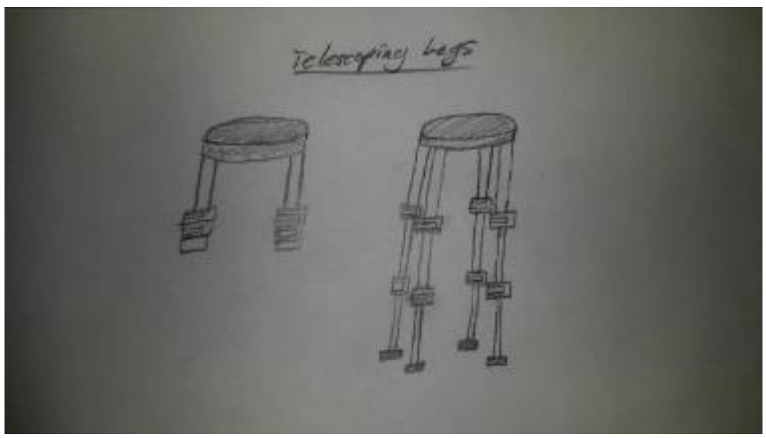


Figure A22: Chair legs telescope to decrease height allowing the chair to be stored easier.

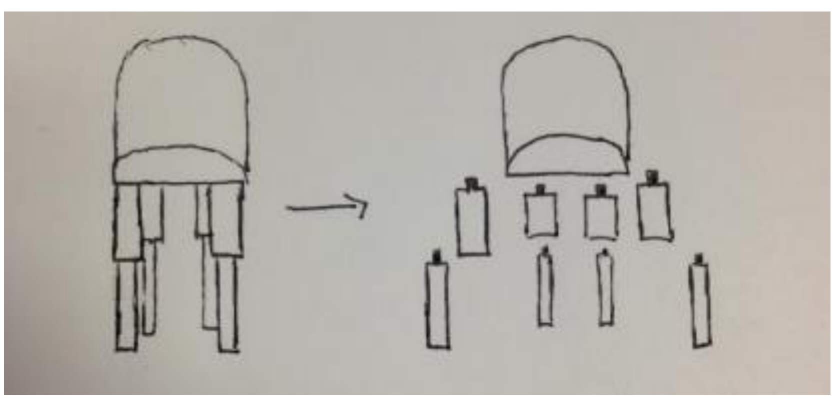


Figure A23: Chair legs break down into pieces

Support Tray

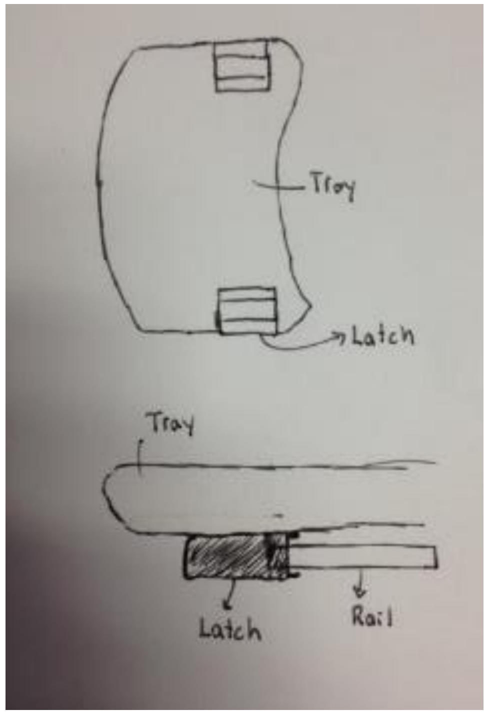


Figure A24: Rails and latch mechanism. The tray must be lined up on the rails in order to be latched into place.

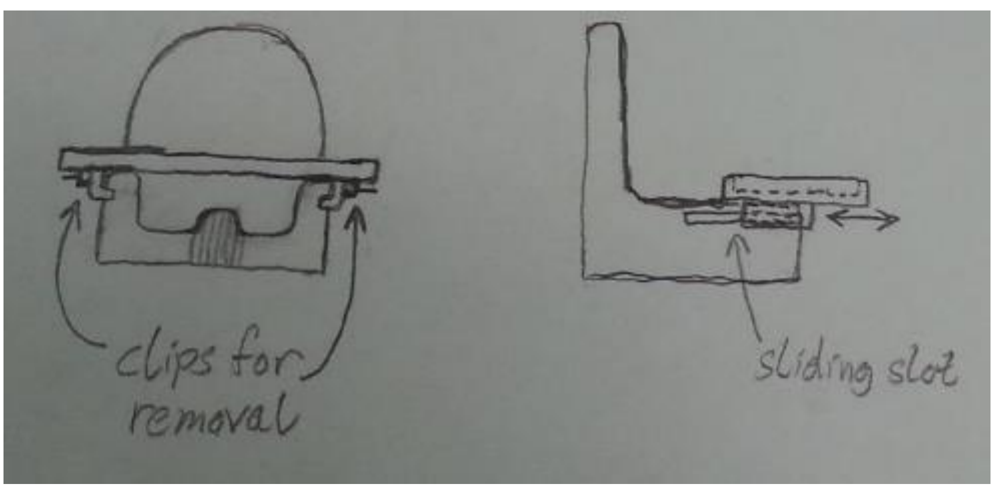


Figure A25: Clips with separate adjustability. The tray can be placed on the chair from above without alignment.

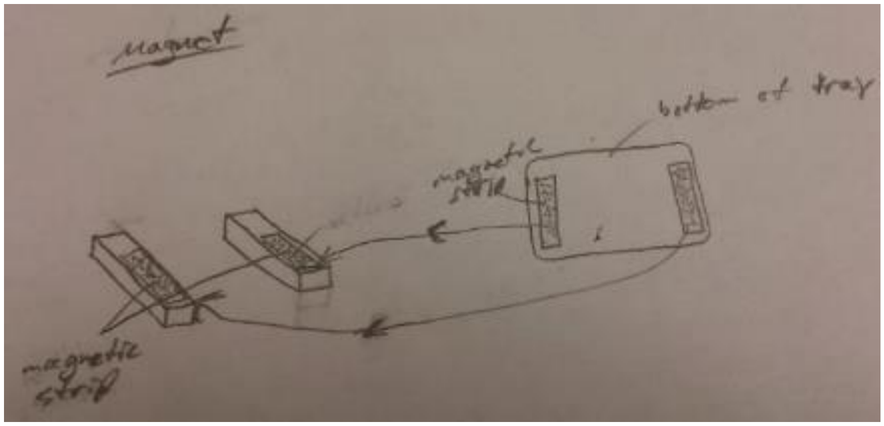


Figure A26: The tray is attached to the tray and held in place by magnetic forces

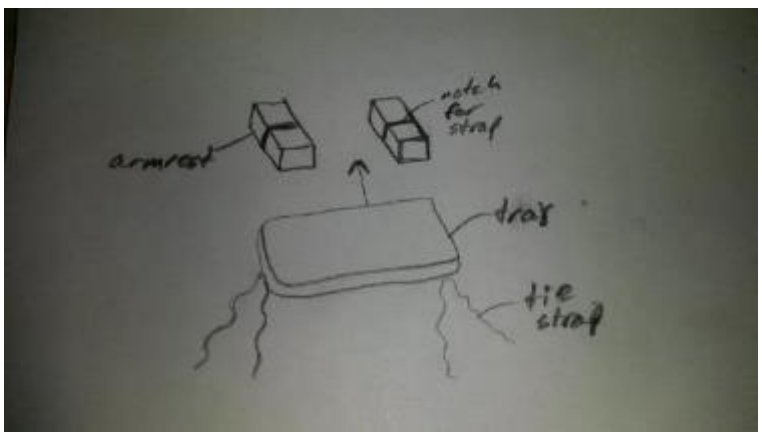


Figure A27: The tray is attached to the chair using tie straps

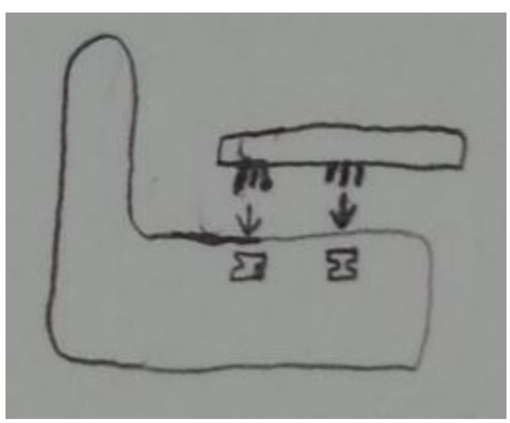


Figure A28: The tray is attached to the chair using buckles

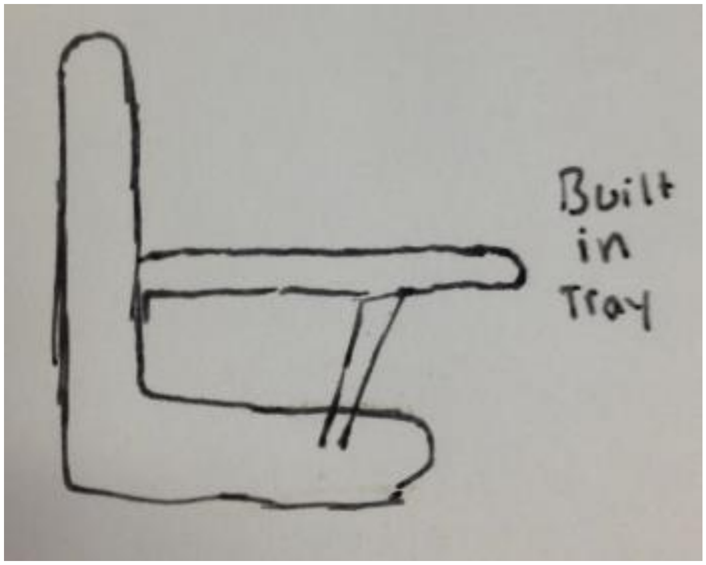


Figure A29: The tray is built in with no adjustability and cannot be removed

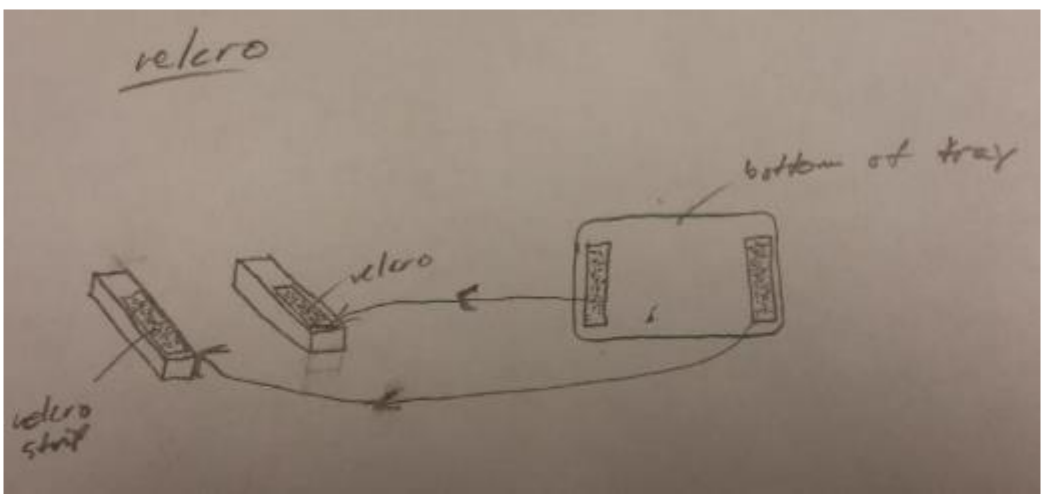


Figure A30: The tray is attached to the chair with Velcro, and its position can be varied

Concept Selection

Pugh Charts

Restraint Pugh Chart								
Criteria	Weight	Straps/5 point harness	Lap bar pivoting between legs	Lap bar pivoting from side of seat back	Overhead roller coaster like restraint	Pants/leg hold that child slides into	Sensor that detects when child is standing	Seatbelt sensor to alert guardian when not buckled
Feasibility	3	0	0	0	0	0	-1	-1
Cost	2	0	0	0	0	-1	-1	-1
Effectiveness	4	0	0	0	0	0	0	0
Manufacturability	2	0	0	0	0	0	-1	-1
Simplicity	5	0	1	1	1	1	-1	-1
Adjustability	3	0	0	-1	0	-1	0	0
Ease of Cleaning	1	0	1	1	1	-1	0	0
Durability	3	0	1	1	1	0	-1	-1
Total		0	9	6	9	-1	-15	-15

Restraint Pugh Chart								
Criteria	Weight	Sticky Chair material	Net that catches child	Magnets/magnetic vest	Electric shock	Inflatable mat on floor around high chair	Leg holes in chair	Lap bar pivoting from outside of legs
Feasibility	3	-1	-1	-1	-2	-1	0	0
Cost	2	-1	-1	-1	-1	-1	1	0
Effectiveness	4	-1	-1	0	0	-1	0	0
Manufacturability	2	-1	-1	-1	-1	-1	0	0
Simplicity	5	1	-1	-1	-1	-1	1	1
Adjustability	3	0	0	0	0	0	-1	1
Ease of Cleaning	1	-2	-1	0	0	1	1	1
Durability	3	-1	1	0	-1	-1	1	0
Total		-11	-14	-12	-18	-18	8	9

Figure A31: Restraint Pugh chart used to narrow down amount of restraint system designs for the final concept

Support Pugh Chart					
Criteria	Weight	Cushion	Bungie cords	Wood	Formed plastic
Feasibility	3	0	-1	0	0
Cost	2	0	-1	-1	0
Effectiveness	5	0	0	0	0
Manufacturability	2	0	0	0	0
Simplicity	4	0	0	0	0
Total		0	-5	-2	0

Figure A32: Support Pugh chart used to narrow down seat materials

Stability Pugh Chart						
Criteria	Weight	4 Legs	3 legs	3 Legs+Wheels	4 legs + wheels	Single pole + wide base
Feasibility	3	0	0	0		0
Cost	2	0	0	-1	-1	-1
Effectiveness	5	0	-1			0
Manufacturability	2	0	0	-1	-1	-1
Simplicity	4	0	1	-1	-1	1
Total		0	-1	-8	-8	0

Figure A33: Stability Pugh chart used to narrow down leg designs and configurations

Reduce Space Pugh Chart				
Criteria	Weight	Folds	Telescoping legs	Breaks down into pieces
Feasibility	3	0	0	0
Cost	2	0	-1	0
Effectiveness	5	0	0	0
Manufacturability	2	0	-1	0
Simplicity	4	0	-1	-1
Total		0	-8	-4

Figure A34: Reduce Space Pugh chart used to narrow down mechanisms to conserve space

Support Tray Pugh Chart								
Criteria	Weight	Rails + latch	Velcro	Magnets	Tie straps	Buckles	Built in	Clips + separate adjustability
Feasibility	3	0	0	0	0	0	0	0
Cost	2	0	1	-1	1	0	1	0
Effectiveness	5	0	-1	0	-1	0	-2	0
Manufacturability	2	0	1	0	0	0	1	-1
Simplicity	4	0	0	-1	-1	-1	1	1
Total		0	-1	-6	-7	-4	-2	2

Figure A35: Support Tray Pugh chart used to narrow down mechanisms to attach tray

Simplified Morphological Analysis

Restrain child	Lap bar pivoting between legs	Overhead roller coaster like restraint	Leg holes in chair	Lap bar pivoting from outside of legs
Support child	Cushion	Formed Plastic		
Ensure Stability	4 Legs	Single pole + wide base		
Reduce Space	Folds			
Support Tray	Clips + separate adjustability	Rails + latch		

Figure A36: Resulting simplified morphological analysis table after narrowing down ideas using Pugh charts

Concept Selection

	Restrain Child	**Support Child**	**Ensure Stability**	**Reduce Space**	**Support Tray**
Datum	5 point harness	Cushion	4 legs	folds	Rails + latch
Concept 1	Lap bar pivoting between legs	Cushion	4 Legs	Folds	Clips + separate adjustability
Concept 2	Lap bar pivoting between legs	Formed Plastic	Single pole + wide base	Folds	Rails + latch
Concept 3	Overhead roller coaster like restraint	Cushion	Single pole + wide base	Folds	Clips + separate adjustability
Concept 4	Overhead roller coaster like restraint	Formed Plastic	4 Legs	Folds	Rails + latch
Concept 5	Leg holes in chair	Cushion	4 Legs	Folds	Rails + latch
Concept 6	Lap bar pivoting from outside of legs	Cushion	4 Legs	Folds	Clips + separate adjustability

Figure A37: Table of selected generated concepts. Each section was chosen from the simplified morphological analysis table

Concept Pugh Chart									
Criteria	Weight	Datum	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
Feasibility	3	0	0	0	0	0	0	0
Cost	2	0	-1	-1	-1	-1	1	-1
Effectiveness	4	0	0	0	0	0	-1	0
Manufacturability	2	0	0	0	0	0	1	0
Simplicity of Restraint	5	0	2	2	2	2	1	1
Simplicity of Tray	2	0	1	0	1	0	0	1
Mobility of child	3	0	1	1	0	0	-1	1
Adjustability	3	0	0	0	0	0	-1	0
Ease of Cleaning	1	0	1	1	1	1	1	1
Durability	3	0	1	1	1	1	1	1
Comfort	2	0	1	0	1	0	1	1
Total		0	19	15	16	12	5	14

Figure A38: Pugh chart used to rank concepts and ultimately choose our final concept

Appendix B: Engineering Analysis

RatchetSim_1.m*

```
%Ratchet Teeth Strength Calculation

sig = 193;          %yield-strength of Al
wid = 12.7;         %face width (mm)
clicks = .5;        %clicks per degree
dpth = 1;           %tooth depth (mm)
Sf = 1.5;           %safety
od = 7;             %OD (in)

odmet = od*25.4;
rte = (odmet-(2.*dpth))./2000;
teeth = 360*clicks;

rtln = dpth*tan((60-(360/teeth))*((2*pi)/360));
Fb = sig.*((wid.*rtln)./6).*(1./dpth).*(1/Sf);

T = Fb.*rte

```

Figure B1: Code used in initial analysis of strength of ratchet.

ToothSim_1.m

```
x=[0:0.001:0.05];


N = 550; %Force
L = 0.00127; %Length of tooth
p = N./L;
moment = 0.5.*p.*(L-x).^2; %Moment
b = 0.0127;
h = x.*tan(60.*(2.*pi)/360);
I = (b.*(h.^3))./12; %Second Moment of Area
sigma = (moment.*(h./2))./I; %Stress

plot(x,sigma)
max(sigma)
```

Figure B2: Code used in analysis of strength of ratchet tooth.

Failure Modes and Effect Analysis (FMEA)

To test the safety of our design we conducted a failure modes and effect analysis (Table B1 next page). All risk priority numbers were below 30 which means that they are reasonable and do not pose a high risk. The aspects of our design with the highest risk involved the user properly engaging the restraint system. The specific functions with the highest risk were the lap bar's ability to restrain the child and the high chair's ability to hold the child which are both directly related. Both of these aspects require the parent or guardian to properly adjust and lock the lap bar in place. If this is done incorrectly failure will occur and the child could fall out of the high chair and be injured. To prevent this from happening, we have attempted to create as simple of a design and process as possible. We believe that if our design is simple and if it is easy to restrain the child then minimal injuries will occur. Because the main focus of our project has been safety, we have been designing for safety and low risk since the beginning. Therefore, we do not need to implement any risk reduction methods.

Table B1: Failure Modes and Effect Analysis of our lap bar restraint mechanism. All risk priority numbers were below 30 which means that they are reasonable. For this reason we did not need to take any actions to improve the safety of our design.

Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s) / Mechansim(s) of Failure	Occur	Current Design Controls	Detec	R.P.N.	Recommended Action(s)	Responsiblity & Target Completion Rate	Actions Taken	Sev	Occ	Det	R.P.N.
Telescoping Bar																
Adjusts to size of child	Bar does not telescope	Restraint system does not fit properly and the child can fall out	9		Material is stuck between two moving pieces	1	Tight fit between bars to prevent material from entering between the bars	1	9	None						
Lock	Pin breaks or not fixed correctly	The telescoping bar will not stay in place and not fit properly. This can cause child to fall out	9		Fatigue of pin or user does not correctly engage pin	1	Pin material can withstand expected loads with safety factor	1	9	None						
Lap Bar																
Prevents sliding	Not adjusted properly	Allows child to slide	9		User does not correctly engage lap bar	2	Simple to engage lab bar	1	18	None						
Prevents standing	Not adjusted properly	Allows child to stand	9		User does not correctly engage lap bar	2	Simple to engage lab bar	1	18	None						
Locking Mechanism									0							
Prevents backdriving of lap bar	Pawl does not lock into place	Restraint system does not fit properly and the child can fall out	9		Fatigue of ratchet and pawl or exposure to very large forces	1	Ratchet and pawl materials can withstand expected loads with safety factor	1	9	None						
lock in many different positions	Ratchet teeth failure	Restraint system does not fit properly and the child can fall out	9		Fatigue of ratchet	1	Ratchet and pawl materials can withstand expected loads with safety factor	1	9	None						
Release Mechanism									0							
Releases lock	Release pin or lever breaks	Child will be trapped in high chair	5		Fatigue of release mechanism	1	Pin material can withstand expected loads with safety factor	1	5	None						
High Chair									0							
Holds Child	Restraint system fails	child falls out	9		User does not correctly engage lap bar	2	Simple to engage lab bar	1	18	None						
Elevate Child	Legs break	chair falls	10		Fatigue of legs or exposure to large forces	1	Legs of high chair meet ASTM stability standards	1	10	None						

Appendix C: Engineering Drawings, Manufacturing Plans, and Bill of Materials

We created manufacturing plans for all of our parts (Figures C4-C8). Using the water jet was the best way to manufacture the small precise details of the ratchet, pawl, side plate and base plate. The precise holes in all parts were later finished using the mill. The telescoping bar was purchased and cut to size using the band saw. Because of the irregular shapes of the lap bar, 3D printing was the best option for manufacturing. Because this process can take a significant amount of time, we created a balsa wood model of the lap bar using a hand saw and sand paper. Drawings for these parts can be seen in Appendix C. The bill of materials was also created for all of these parts (Table C1).

Engineering Drawings

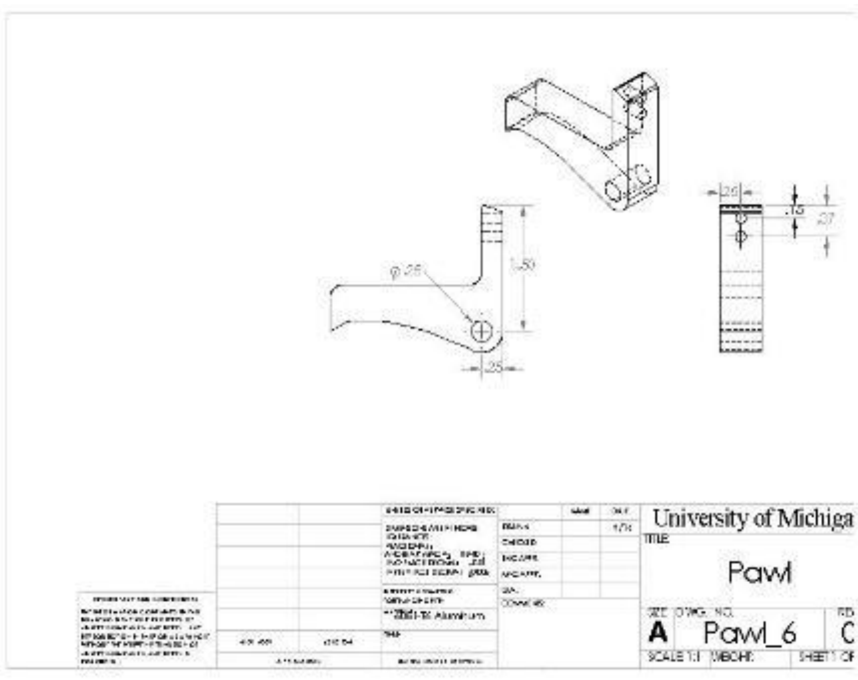


Figure C1: Engineering drawing of pawl

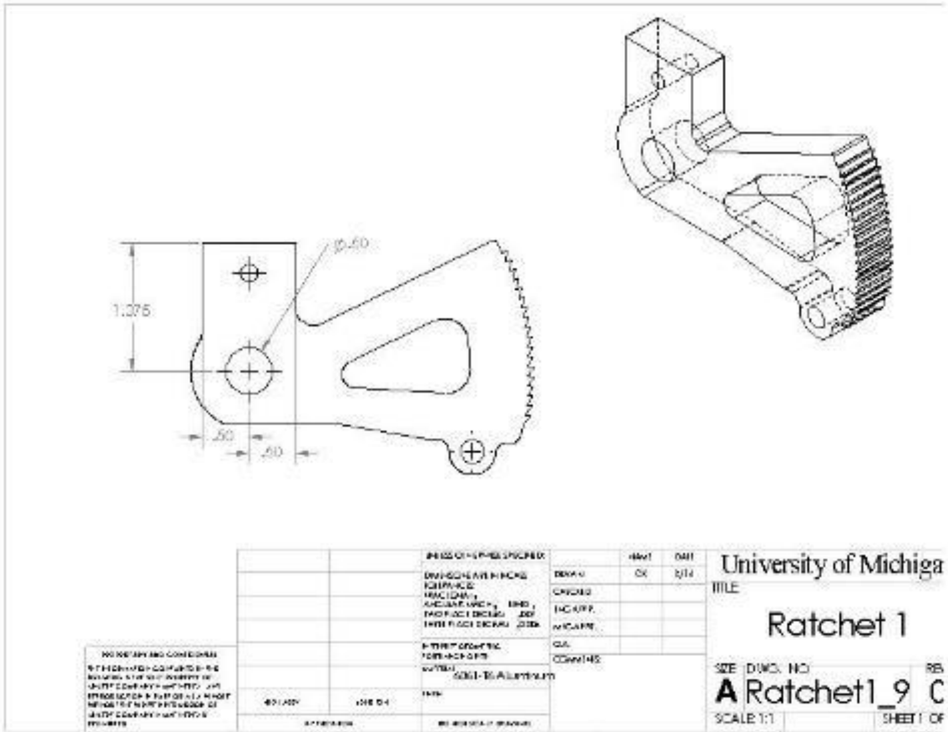


Figure C2: Engineering drawing of ratchet

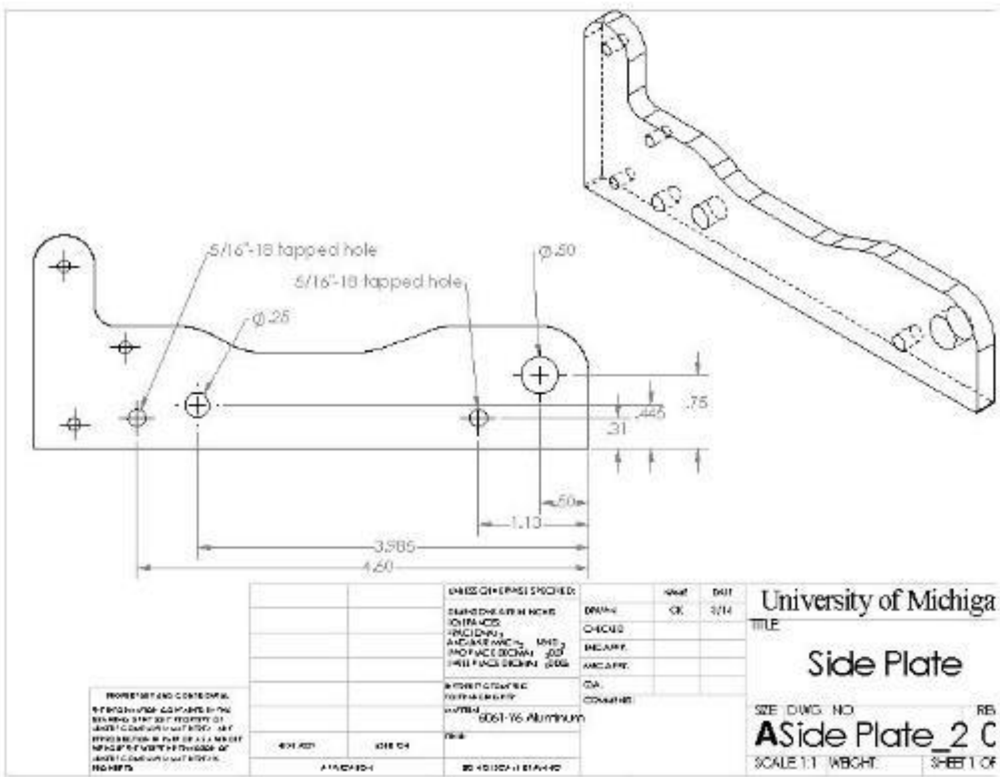


Figure C3: Engineering drawing of side plate

Manufacturing Plans

Manufacturing Plan

Part Number: 01 Revision Date: 3/15/2015

Part Name: Pawl

Team Name: Team 10

Raw Material Stock: 6061-T6 Aluminum, .5 x 6 x 12

Step #	*Process Description*	*Machine*	*Fixtures*	*Tool(s)*	*Speed (RPM)*
1	Waterjet	Waterjet			
2	Install drill chuck and secure part in vise	Mill	Vise	Drill chuck	
3	Locate pilot hole from water jet	Mill	Vise	Drill size 1	
4	Drill Hole	Mill	Vise	Drill size 1	1200
5	Ream Hole	Mill	Vise	0.251" reamer	100
6	Remove from vise	Mill	Vise		
7	Flip part and mount in vise	Mill	Vise		
8	Use edgefinder to locate holes	Mill	Vise	edgefinder	1000
9	Centerdrill and drill hole	Mill	Vise	centerdrill, 1/8" drill	1600
10	Deburr edges as needed	Mill	Vise	file, deburring tool	

Figure C4: Manufacturing plan for the pawl

Manufacturing Plan

Part Number: 02 Revision Date: 3/15/2015
Part Name: Ratchet
Team Name: Team 10

Raw Material Stock: 6061-T6 Aluminum, .5 x 6 x 12

Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)
1	Waterjet	Waterjet			
2	Install drill chuck and secure part in vise	Mill	Vise	Drill chuck	
3	Locate pilot hole from water jet	Mill	Vise	Drill size 15/32"	
4	Drill Hole	Mill	Vise	Drill size 15/32"	600
5	Ream Hole	Mill	Vise	0.5" reamer	100
6	Remove from vise	Mill	Vise		
7	Deburr edges as needed	Mill	Vise	file, deburring tool	
8	Press fit bushing	arbor press			

Figure C5: Manufacturing plan for the ratchet

Manufacturing Plan

Part Number: 03 Revision Date: 3/15/2015
Part Name: Lap bar
Team Name: Team 10

Raw Material Stock: Balsa Wood 3" x 3" x 12"

Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)
1	Retrieve balsa wood block				
2	Use saw to cut to size and rough shape			hand saw	
3	Sand to desired shape			sand paper	

Figure C6: Manufacturing plan for the lap bar

Manufacturing Plan					
Part Number: 04				Revision Date: 3/15/2015	
Part Name: Base Plate					
Team Name: Team 10					
Raw Material Stock: 6061-T6 Aluminum, .25 x 6 x 12					
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Waterjet	Waterjet			

Figure C7: Manufacturing plan for the base plate

Manufacturing Plan					
Part Number: 05				Revision Date: 3/15/2015	
Part Name: Side Plate					
Team Name: Team 10					
Raw Material Stock: 6061-T6 Aluminum, .25 x 6 x 12					
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Waterjet	Waterjet			
2	Install drill chuck and secure part in vise	Mill	Vise	Drill chuck	
3	Locate pilot hole from water jet	Mill	Vise	Drill size 15/32"	
4	Drill Hole	Mill	Vise	Drill size 15/32"	600
5	Ream Hole	Mill	Vise	0.5" reamer	100
6	Locate pilot hole from water jet	Mill	Vise	Drill size 1	
7	Drill Hole	Mill	Vise	Drill size 1	1200
8	Ream Hole	Mill	Vise	0.251" reamer	100
9	Remove from vise	Mill	Vise		
10	Deburr edges as needed	Mill	Vise	file, deburring tool	
11	Drill holes to tap	mill	vise	drill size 16	1200
12	Tap holes	mill	vise	5/16"-18 tap	

Figure C8: Manufacturing plan for the side plate

Table C1: Bill of Materials

#	Item Name	Source Material	Item Number	Manufacturer	Quantity of Stock	Quantity of Item	Cost (USD)	Bought for
1	Cozy Dinette™ Highchair	Off Shelf	1764373	Graco	1	1	99.99	35(USD) at Once upon a child
2	Shoulder Bolt .25" Diameter	Off Shelf	96126A168	McMaster Carr		1	5.36	
3	Ratchet	Multipurpose 6061 Aluminum, 1/2" Thick, 6" Width, 1' Length	8975K439	McMaster Carr	1 (Share with pawl)	2	15.53	
4	Pawl	Multipurpose 6061 Aluminum, 1/2" Thick, 6" Width, 1' Length	8975K440	McMaster Carr	1 (share with ratchet)	2	15.53	
5	Telescoping Bar	Off Shelf			1	1	14.99	14.99 from Amazon
6	Lap-bar	Balsa Wood 3" x 3" x 12"	B7016	Midwest Products	1	1	11.5	11.5 from Amazon
7	Side Plate	Multipurpose 6061 Aluminum, 1/4" Thick, 6" Width, 6" Length	9246K423	McMaster Carr	1	1	8.39	
8	Base Plate	Multipurpose 6061 Aluminum, 1/4" Thick, 6" Width, 12" Length	8975K439	McMaster Carr	1	1	15.53	
9	Springs	Precision Stainless Steel Extension Spring, 1.0" Length, .375" OD, .045" Wire Diameter	9433K74	McMaster Carr	3	3	4.77	
10	Sleeve Bearing for ratchets	SAE 841 Bronze Sleeve Bearing, for 3/8" Shaft Diameter, 1/2" OD, 1" Length	6391K178	McMaster Carr	2	2	2.76	

Appendix D: Engineering Change Notices

Release Mechanism

The only change from our final design to our prototype is the addition of a release mechanism. Prior to our prototype we thought that attaching a wire to the pawls and pulling on the wire would be an adequate release mechanism. After assembling our prototype we realized that pulling the wire is difficult and requires a significant amount of force. To remedy this problem we designed a lever that attaches to the back of the high chair and gives the user a mechanical advantage. Since there are not any specific changes in design but instead new parts, the engineering drawings for each release mechanism component is detailed in Figures D1-D3. The lever baseplate attaches to the back of the chair. The lever shaft goes through the lever handle and is attached to the baseplate by two brackets (Figure 22).

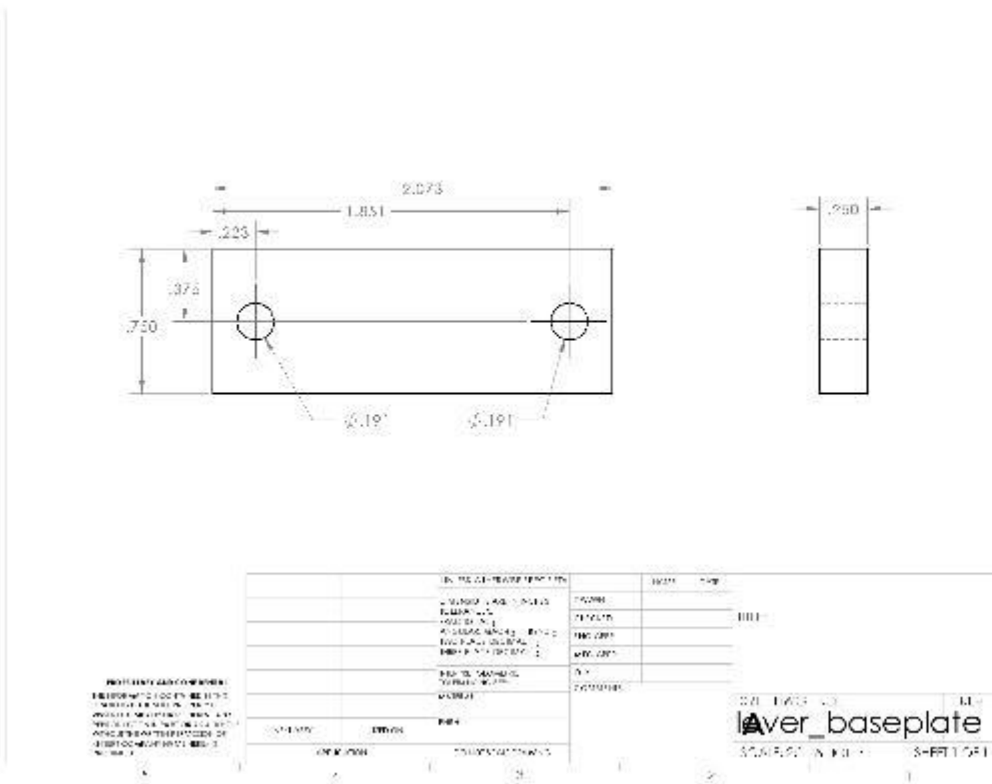


Figure D1: Engineering drawing of lever baseplate

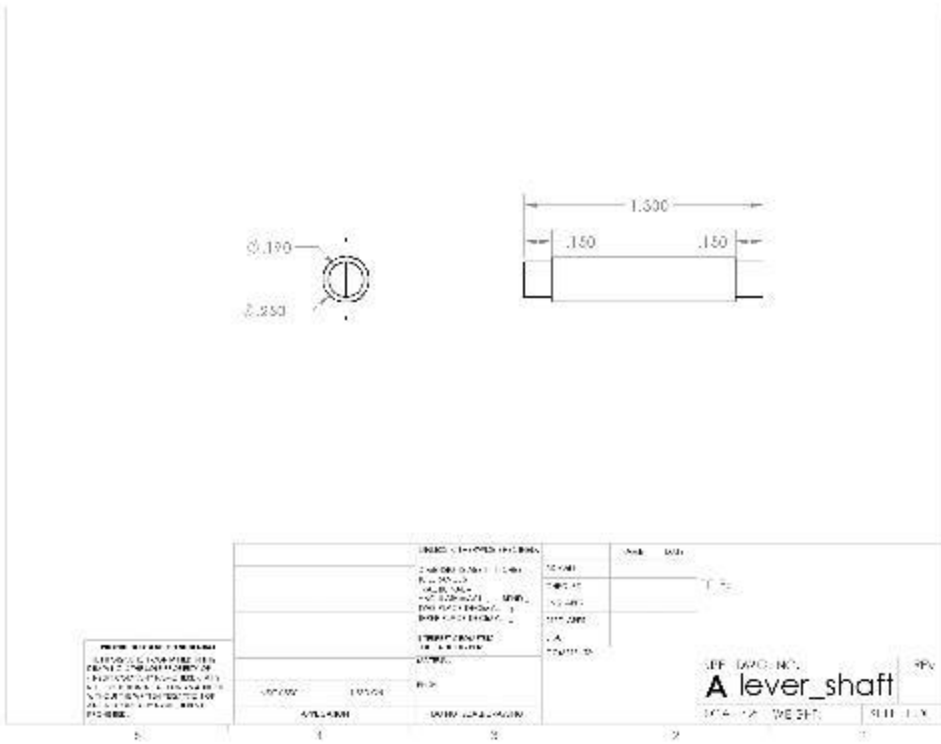


Figure D2: Engineering drawing of lever shaft

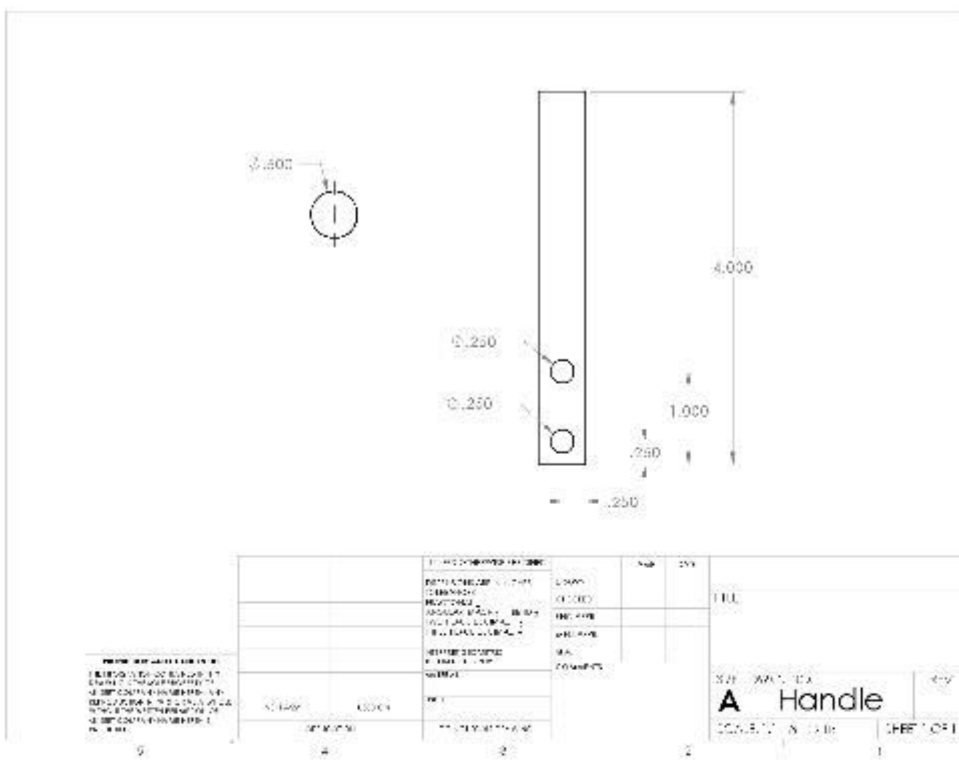


Figure D3: Engineering drawing of lever handle

Appendix E: Validation Protocol

Timing Tests

What will you need to measure?

We will need to measure the number of steps it takes to put the dummy in the high chair and time how long this process takes. We will then measure the number of steps it takes to properly secure the restraint system and the time it takes to complete this. In a separate test we will time how long it takes to adjust the restraint system to fit the dummy.

W*hat equipment will you use?*

We will use our purchased high chair, which has a five-point harness as a control and our new designed lap bar. We will also use a stuffed animal to simulate a child dummy. We will keep track of time using stopwatches on our phones.

What are the basic steps you will follow in order to acquire your data?

First we will ask a random subject to participate in our test. We will then record the amount of steps and time it takes for them to place the dummy into the high chair. We will repeat the same measurements for when the subject attempts to restrain the dummy using first the five point harness and second our lap bar design. Then we will place the dummy in the high chair and put the lap bar on the lowest adjustment setting. We will time how long it takes the subject to adjust the lap bar to fit the dummy.

How will you process your data in order to find a useful and significant result?

We will record all of the number of steps and all of the times for each part of the test and put the results in a table. This will allow us to compare the time it takes to restrain a child with a five-point harness with our lap bar design.

Sharp Point Test

What will you need to measure?

We need to measure whether there are any sharp points on our restraint system or high chair that would not pass the sharp point test

What equipment will you use?

We will use our high chair and we will test for sharp points ourselves instead of using a sharp point tester. In the future a sharp point tester should be used.

What are the basic steps you will follow in order to acquire your data?

We will check the entire chair and restraint system for sharp points. With more time and resources we would conduct the tests described in 16 CFR 1500.48 and 16 CFR 1500.49 with the sharp point tester.

How will you process your data in order to find a useful and significant result?

We will record where any sharp are found if any are found. We will then attempt to fix these points. If there are no sharp points we will record that no sharp points were found.

Pinch Point Test

What will you need to measure?

We will need to measure any point on the chair that admits a probe greater than 0.210 in (5.3 mm) and less than 0.375 in (9.5 mm) in diameter at any accessible point throughout the range of motion of such parts. This defines a pinch point according to ASTM standards.

What equipment will you use?

We will use our high chair with measuring equipment to measure where pinch points could occur.

What are the basic steps you will follow in order to acquire your data?

We will measure any point on the high chair that could classify as a pinch point and record the results.

How will you process your data in order to find a useful and significant result?

We will record any results that classify as pinch points. We will then attempt to fix any pinch points that occur. If there are no pinch points we will record that no pinch points were found.

Restraint System Tests

What will you need to measure?

We will need to test that our restraint system can withstand the applied horizontal and vertical loads. We also need to measure that there are no vertical gaps that allow free passage of the child's legs.

What equipment will you use?

We will use our high chair and restraint system along with measuring tools and a force gauge. We will use a stuffed animal as a dummy since we could not obtain a CAMI doll.

What are the basic steps you will follow in order to acquire your data?

We will do the horizontal pull test first. Because we do not have a CAMI doll to pull on the centerline of the leg we will pull horizontally on the lap bar itself and make sure the dummy is not given enough space to move. We will pull with a gradual force of 200N for 5 seconds and hold at 200N for 10 seconds. We will repeat this test for a total of 5 times. The vertical test is exactly the same except the force will be applied vertically to the lap bar. We will then measure the vertical gaps where the legs would be to make sure they fall within the standards.

How will you process your data in order to find a useful and significant result?

During each test we will check to make sure the dummy does not have enough room to move. We will record these results in our lab notebook after each test. If there are any failures we need to find out why the failure is occurring and fix it. If there are no failures we will record that our restraint system passed the ASTM standards.

Structural Integrity Test

What will you need to measure?

We will first test whether the chair and restraint system are negatively affected by the 100lbs of force. We will then measure the force it takes to cause the high chair to tip with and without our restraint system attached.

What equipment will you use?

We will use our high chair, a 100lb weight and a luggage scale to complete these tests.

What are the basic steps you will follow in order to acquire your data?

We will first obtain our high chair without our new restraint system attached. We will then use a luggage scale attached to the side of the chair to see the minimum amount of force it takes to make the high chair tip or leave the ground. This measurement will be repeated three times. We will then attach our restraint system to the chair and repeat the same measurements. Then we will place a 100lb weight on the seat of the high chair and leave it for 60s. This will be repeated five times.

How will you process your data in order to find a useful and significant result?

We will compare the two force measurements required to tip the high chair using a table. We want the high chair with our restraint system to tip at the same or higher force than the high chair without the restraint system. For the 100lb weight test we will record any negative effects that happen while the weight is on the chair. If there are no negative effects we will record that there were no issues and that the high chair passed the structural integrity test.

Tray Integrity Tests

What will you need to measure?

We will test to see if the tray can be attached in all of its positions and in no way is hindered by the lap bar. We will also test that the tray can withstand the applied loads which it should be able to withstand without the lap bar.

What equipment will you use?

We will use our high chair and a force gauge for the applied loads.

What are the basic steps you will follow in order to acquire your data?

We will try attaching the tray in all positions while the lap bar is deployed to make sure that the lap bar does not hinder the tray's performance. We will then pull with a gradual horizontal force of 200N for 5 seconds and hold at 200N for 10 seconds on the middle top part of the tray while it is attached. We will repeat this test for a total of 5 times.

How will you process your data in order to find a useful and significant result?

We will record the tray's functionality in each position and whether its function is hindered by the lap bar. If the lap bar cannot be attached then we will record these results and try to make changes to the lap bar to fix this problem. After each load test we will record whether the tray stays on or moves in any way. If the tray is not affected by the loads we will record that it passed the tray tests.

Aesthetically Appealing and Marketability Test

What will you need to measure?

We need to measure the aesthetic appeal of our high chair and test whether our product will be marketable and desired by consumers. We will accomplish this by surveying people shopping at child product stores like Babies R Us. These people are the ones most likely to be purchasing a high chair.

What equipment will you use?

We will need our high chair design and a survey that we created (Figure E1). No other special equipment will be necessary.

What are the basic steps you will follow in order to acquire your data?

We will stand outside of child product stores and ask customers if they want to participate in our survey. If they do then we will ask them to take a look at our high chair design and fill out a quick survey questionnaire.

How will you process your data in order to find a useful and significant result?

We will record all the results and perform statistical analysis on the data. We will find the mean of the answers to see what most people think of our project.

ME450 Safer High Chair Survey

1. Does our high chair look safe? (Y/N)

2. On a scale of 1 to 10 how would you rate the aesthetics of our high chair?

3. Would you purchase this high chair for your child? (Y/N)

Any Questions/Concerns:

Figure E1: Aesthetically appealing and marketability survey

Appendix F: Validation Results

Observational Requirements

Child is properly restrained

The specification required at least one waist and one crotch restraint. Our lap bar design achieves this specification. The telescoping bar acts as a crotch restraint and the lap bar acts as a waist restraint

Promote use of the safety system

The specification required at least one mechanism to prevent use when the restraint system was not deployed. We accomplished this by making it impossible to attach the tray when the lap bar was in the upright position (Figure F1).

Figure F1: The lap bar in the upright position prevents the tray from being attached. This promotes the use of the restraint while the high chair is being used.

Child cannot slide out of bottom of chair

The specification required that there shall be no vertical gap between the passive crotch restraint and either tray, front torso support, or seating surface that allows free passage of a 1.5-in. (38-mm) diameter by 3-in. (76-mm) long rod from one leg opening to the other. Our high chair achieved all of these specifications.

Easy to clean the different parts of the high chair

The specification required a removable table, washable liner, 100% non-absorbent material, no recesses (width <1/8 in and recessed >1/16 in) that can store dropped food. Our high chair achieved all of these specifications.

Comfortable for child to sit in chair

The specification required a cushion thickness greater than 0.5cm. Our high chair's cushion achieved this specification with a thickness of 1 cm.

Ability to fold up and store high chair

The specification required the footprint area to be reduced by less than 50% of in use area when not in use. Our high chair had the ability to fold and achieved this specification.

Light weight

The specification required the weight of the high chair to be less than 30 pounds. The high chair we purchased was originally 18.4 pounds before adding our restraint system. After we added our restraint the high chair was 20.8 pounds. Our high chair is below specification and only added 2.4 pounds.

Cost efficient

The specification required the cost of the high chair to be less than $150. It was difficult to determine what the cost of our high chair would be because our manufacturing process would be very different than a mass production process. We also do not know what price a company would charge for our high chair. We believe that our high chair could be brought within this price range if the restraint system was manufactured into the high chair instead of being assembled onto an existing high chair. Most parts could be made using injection molding and the locking mechanism could be made by casting or a similar process. This would greatly reduce the price and make it affordable for all families. The addition of an integrated lap bar restraint might increase costs by around $50 which would make it more expensive but still affordable.

Timing Tests

Easy to get child in and out

The specification required that it takes one step to put the child in the chair and takes less than thirty seconds. We accomplished this requirement as seen in the results Table F1.

Table F1: These results show that the time to put the child in is much less than 30s.

Test Number	Number of Steps	Time (s)
1	1	1.5
2	1	0.5
3	1	0.5
4	1	0.5
5	1	1
Average	**1**	**0.8**

Restraint/safety system simple and fast to use

The specification required that it takes less than three steps and less than 45 seconds to restrain the child. We accomplished this requirement and proved that our restraint is much faster and easier to use than the five point harness (Table F2).

Table F2: These results show that not only does our lab bar restrain meet requirements but it is ten times faster than the five point harness and requires three less steps to use.

	5-Point Harness		Lab Bar Restraint	
Test Number	Number of Steps	Time (s)	Number of Steps	Time (s)
1	4	23	1	1.5
2	4	22	1	0.6
3	4	21.5	1	1.5
4	4	17.5	1	2.5
5	4	43	1	4
Average	**4**	**25.4**	1	**2.02**

Safety System easy to adjust and maintains adjustment between uses

The specification required the adjustment time to be less than three minutes. We accomplished this requirement as seen in the results Table F3.

Table F3: These results show that the adjustment time is much faster than the requirement

Test Number	Time (s)
1	6.25
2	4
3	5
4	4.5
5	5.5
Average	**5.05**

Sharp Point Test

The specification required that our high chair passed the sharp point test detailed in ASTM 5.1 and 16 CFR 1500.48. Because we did not have a sharp point tester, we manually tested for sharp points (Figure F2). We did not find anything that would be described as a sharp point.

Figure F2: Manually testing our high chair for sharp points

Pinch Point Test

The specification required that there were no pinch points on the chair classified by ASTM 6.7. The slot in the high chair and the telescoping bar itself does qualify as a pinch point. We acknowledge that we created a pinch point and have developed a series of solutions that would be adopted when mass manufacturing the high chair. One example is to cover the slot with material to prevent the child from getting extremities caught in the pinch point. Another example is having hard plastic that covers the slot and moves with the bar as it rotates through its range of motion. In this example there would be no hole for a pinch point so it would be impossible to trap any extremities.

Restraint System Tests

The specification required that we pass the restraint pull tests described in ASTM 6.8. Because we purchased the telescoping bar and its thickness was less than what we originally desired, our strength calculations showed that our restraint might not be able to withstand the applied loads. The locking mechanism was built with a safety factor of nine with these loads but the weak telescoping bar could fracture. Because we did not want to destroy our prototype before the design expo we did not apply the full 200N forces to the lap bar (Figures F4 and F5). If we were to design again we would create our own telescoping bar with a thickness that could withstand the required loads.

Figure F3: (a) Demonstrates our measuring of pinch points on the high chair classified by ASTM standards. (b) An example of a solution to the pinch point problem by covering the slot with a rubberlike material.

Figure F4 & F5: Figure F4 (Left) demonstrates the vertical pull test. Figure F5 (Right) demonstrates the horizontal pull test.

Structural Integrity Test

The specification required that the chair can withstand a load of 100 pounds directed on the seat. We also tested to see the force required to tip the chair over or make the wheels come off the ground. Our high chair withstood the 100 pound load which was backpack filled with 100 pounds of books (Figure F6). Our chair also required an average load of 5.7 pounds to tip compared to a load of 5.3 pounds to tip without our restraint system added. This makes sense because our restraint system added more weight and rigidity to the high chair.

Figure F6: Demonstrates the structural integrity test

Tray Integrity Tests

The specification required that the tray could withstand a horizontal 200 N load. Our tray did withstand the load which proves that our restraint does not affect the trays attachment (Figure F7).

Figure F7: Demonstrates the tray integrity test

Aesthetically Appealing and Marketability Test

The specification required that our high chair scored at least a 5/10 on a likert scale for aesthetic appeal. We traveled to a local children's product store called The Seedling Project and surveyed 15 people using the survey in Figure E1. Our high chair scored a 7.3/10. 100% of people surveyed said the design looked safe and 85% of the people surveyed said that they would purchase our high chair.

Appendix E: Ethical Design and Environmental Impact Statements

Ethical Design Statement

Marcus Brown

We have addressed ethics in our design process. We have applied and upheld the Code of Ethics for Engineers throughout our project. We have held public/user safety at the highest importance. We have limited our work to our areas of training and knowledge. We have acted professionally and objectively and honorably. We have used our skills to produce the best possible solution we were capable of.

Chance Keib

In the design of our high chair we prioritized the safety of the children in the high chair and around the high chair. We followed ASTM standards to minimize sharp edges and pinch points on the chair to increase safety of the child. We designed our high chair in what we believe to be a safer and more effective system than what is currently on the market. Parents and caregivers using the high chair we designed will be able to trust the safety of their children in our design.

At no point in the design, manufacturing, or testing of our high chair up to this point have we used real live children to test our design. Human testing, especially with children can possibly endanger the child. Using children to test our high chair would be highly unethical and unprofessional.

Jake Mathieu

We have addressed ethics in design since the beginning of our project. Our project's purpose is to design a safer high chair that will prevent injuries to children. Since our main focus has been safety from the start, we have always considered ethics in design. To make sure that our solution actually better protected children, we first researched the cause of all high chair injuries. From this research we determined that children who are not properly restrained tend to stand on the high chair and fall. Children are not properly restrained because of the tedious nature of the straps as restraint systems. In order to create an ethical design that better protects children, we decided to design a lap bar restraint that is easier and simpler to use than straps. Throughout the design process we made sure to keep ethics in mind so that we created the safest prototype for children. We also made sure that our lap bar was adjustable for all ranges of children ages six months to two years old. This was an ethical decision because if the lap bar did not fit the child properly they might fall out and be injured. We used anthropometric data to prove our adjustability measurements were accurate and to make sure our restraint encompassed all sizes. After our design was manufactured we made ethical decisions with validation testing. We used the optional ASTM standards for high chairs as a guideline for most of our tests. We made sure that our high chair would be able to pass these standards and therefore be as safe as possible. Another ethical decision was to use a dummy for testing instead of children. This is obviously a safety issue because our design is still a prototype. Overall I believe our team has been very ethical throughout design and has created a better and safer high chair.

Konrad Tech

Throughout the design process of our high chair we upheld the Code of Ethics for mechanical engineers. When deciding on the concept of a high chair we considered many different factors. The most important factors that we considered were effectiveness of the restraint system, and ease of operation. This was an ethical act, as we could have made cost and ease of manufacturing our main priority, which is good for a business, but would ultimately cause injury to the users of our product. After choosing a design concept, we needed to choose the material and dimensions of our product. We conducted preliminary calculations in regards to what stresses our device will be placed under. We made sure that the material we chose would be able to withstand these stresses with a safety factor. We chose to make the parts that underwent large stresses out of aluminum, and by doing this we ensured that there would be no failure of the system and no possibility of the child getting hurt. Finally, when manufacturing our design, we followed our engineering drawings as close as possible so as to avoid the possibility of a malfunction in the function of our device.

Environmental Impact Statements

Marcus Brown

We have made some environmental impact considerations in the creation of our concept and prototype. Where possible, we have avoided the use of materials that negatively impact the environment, such as PVC. The materials we have chosen are recyclable. The primary material used is aluminum, along with steel fasteners and the lap bar made of ABS. To improve our designs impact on the environment, we would use less material and be more efficient in machining, which would use less material and less energy.

Chance Keib

In brainstorming and designing our solution for a safer high chair we didn't put much consideration into the environmental impacts. Our product will have a similar impact to current high chairs on the market. In creating our prototype we purchased a used high chair and added our design to it. The used high chair reduced cost on our project and recycled a chair that may have been thrown out. Our lap bar we designed was made with abs plastic which is recyclable. Our locking mechanism and supports for it are made out of aluminum which is also recyclable.

If we were to manufacture our prototype for consumer markets we would design the entire high chair. This would allow us to use different plastics, choosing ones that are more environmentally friendly and also biodegradable. By using environmentally safe biodegradable plastics if the chair is thrown out instead of recycled the plastics won't cause as much damage to the environment.

In our prototype we used aluminum for the locking mechanism and supporting fixtures. Aluminum is highly recyclable and has little negative impact on the environment. Recycling aluminum uses only 5% of the energy used to make aluminum from ore. We could use only recycled aluminum to reduce energy costs of producing our high chair.

Jake Mathieu

The environment is very important and it is vital as an engineer to make designs that are conscious of sustainability. This is very difficult to accomplish especially with limited resources and experience. For example, it would have probably been more efficient to make our entire lab bar restraint out of a type of plastic. This would be very difficult for us because we do not have the resources or experience with plastic. Instead we used aluminum, which is not the best material to be on a high chair. To increase the sustainability of the high chair it could be made of recycled plastic or other materials that are not as harmful to the environment. In our design we did make sure to use as little material as possible, which does help the environment. We ordered just as much material as we needed so after machining there was barely any waste. We made sure that our designs were finalized before machining to prevent making the same part multiple times and wasting material. We also tried to attach component to use the least amount of fasteners as possible for easier assembly. One of our main impacts on the environment was instead of making an entire high chair we decided to just focus on the restraint system and purchase a used high chair. This saved a lot of material that would have been used and we recycled a high chair that might have been thrown away. There are many ways to make this design more environmentally friendly. If we file a patent for our design we will try to implement these environmentally friendly ideas.

Konrad Tech

Environmental impact was something that was not considered greatly in the production of our prototype. The materials we used were aluminum for the mechanical components, and ABS plastic for the lapbar. Aluminum is a material that requires a lot of energy to produce, so it has a large initial negative effect on the environment. However, aluminum can be recycled infinitely, so when this product is no longer in use it will not be thrown into a landfill, rather it could be recycled into another aluminum product. ABS plastic is produced from natural gas and petroleum, so obviously the production of ABS is a drain on the world’s resources. ABS is a material that can be recycled, but is not accepted by all recycling facilities so it will most likely end up at a landfill when the user is finished with the high chair.

If we were to manufacture this safer high chair on a much larger scale we would consider environmental impact more. We would probably swap out the aluminum for a material that requires much less energy to produce, but has similar strength properties. Also, our prototype was a bit over engineered in terms of the safety factor on some of the parts. We would ultimately reduce the amount of material being used, while still upholding the function of the device. The ABS plastic that we used could possibly be replaced by a material as easy to mold, but more energy efficient.

Authors

Marcus Brown

Marcus Brown is a fifth year senior, double majoring in Mechanical Engineering and Materials Science & Engineering at the University of Michigan. Marcus plans to work in industry after graduating in May 2015. He is a leading member of The Children of Yost (Michigan Hockey student section) and also enjoys riding motorcycles, snowboarding, and good food.

Chance Keib

Chance Keib is a senior in the Mechanical Engineering program at the University of Michigan. Chance will be graduating in May 2015 and will be starting a career in an engineering field after graduation.

Jake Mathieu

Jake Mathieu is a senior mechanical engineer at the University of Michigan. Jake's hometown is Centerville, Massachusetts but he has always loved Michigan since he moved away at the age of 7. As a co-op in the safety department at the Toyota Technical Center, Jake worked on airbag testing and reliability. This experience sparked his interest in safety and was a leading motivation throughout this project.

Konrad Tech

Konrad Tech is a senior studying Mechanical Engineering at the University of Michigan. He will be graduating in May 2015 and is looking forward to a career in the engineering world. He is a Michigan native who enjoys golf, drum set, bass guitar, and lifting weights. He is excited to work on a project as fulfilling as one that protects children from injury.

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